

Searches in Z: From ZZ to ZH

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Outline

Introduction

- Standard Model and Motivation

Experimental Apparatus

- The Tevatron
- The D0 Detector

Diboson Search at D0

- Signature and Background
- Event Selection
- Instrumental Backgrounds
- Physics Backgrounds
- Limit Setting and Results

Low Mass Higgs Search at D0

- Signatures and Background
- Event Selection
- B-Tagging Jets
- Kinematic Fitting
- Multivariate Classifier
- Results

Diboson Physics

Study of the Electroweak sector:

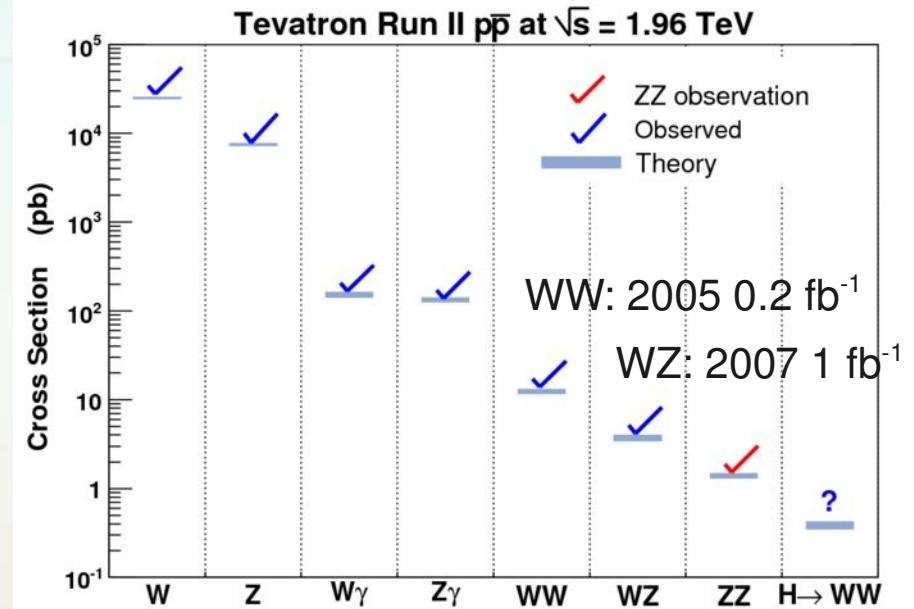
Pair production of W/Z bosons: WW, WZ, and ZZ
Associated production with a photon: W γ and Z γ

Precision tests of the standard model predictions:

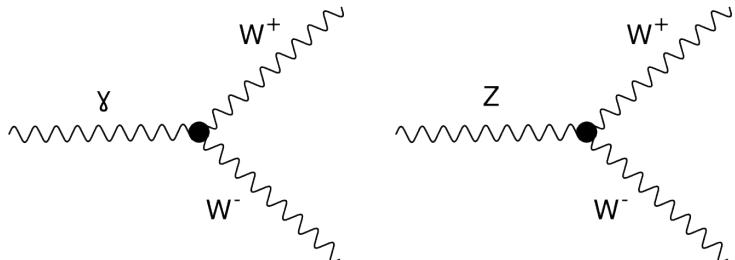
Unexpectedly high cross section could indicate presence of physics beyond the SM.

At the time of this search, ZZ was the last unobserved diboson (non-Higgs) process at the Tevatron.

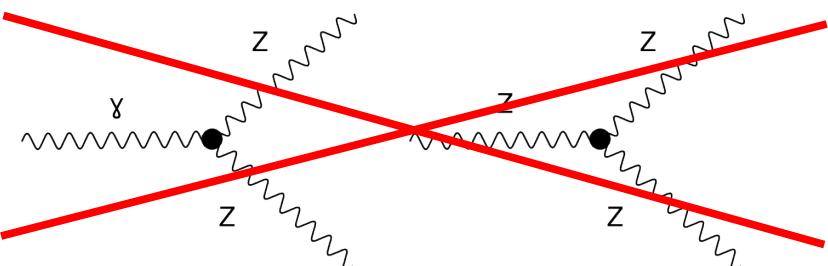
No trilinear gauge couplings (suppressed at the tree level)



Allowed in the Standard Model

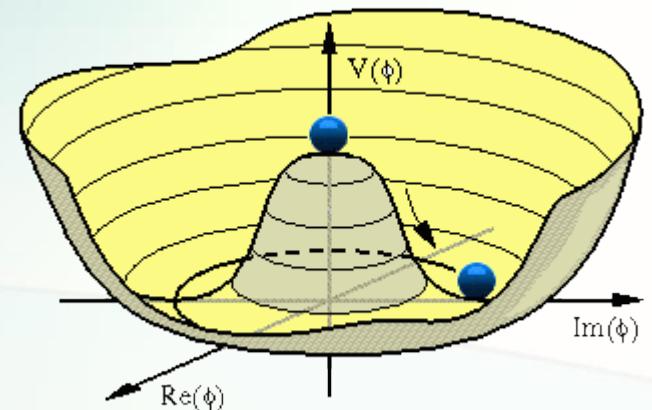
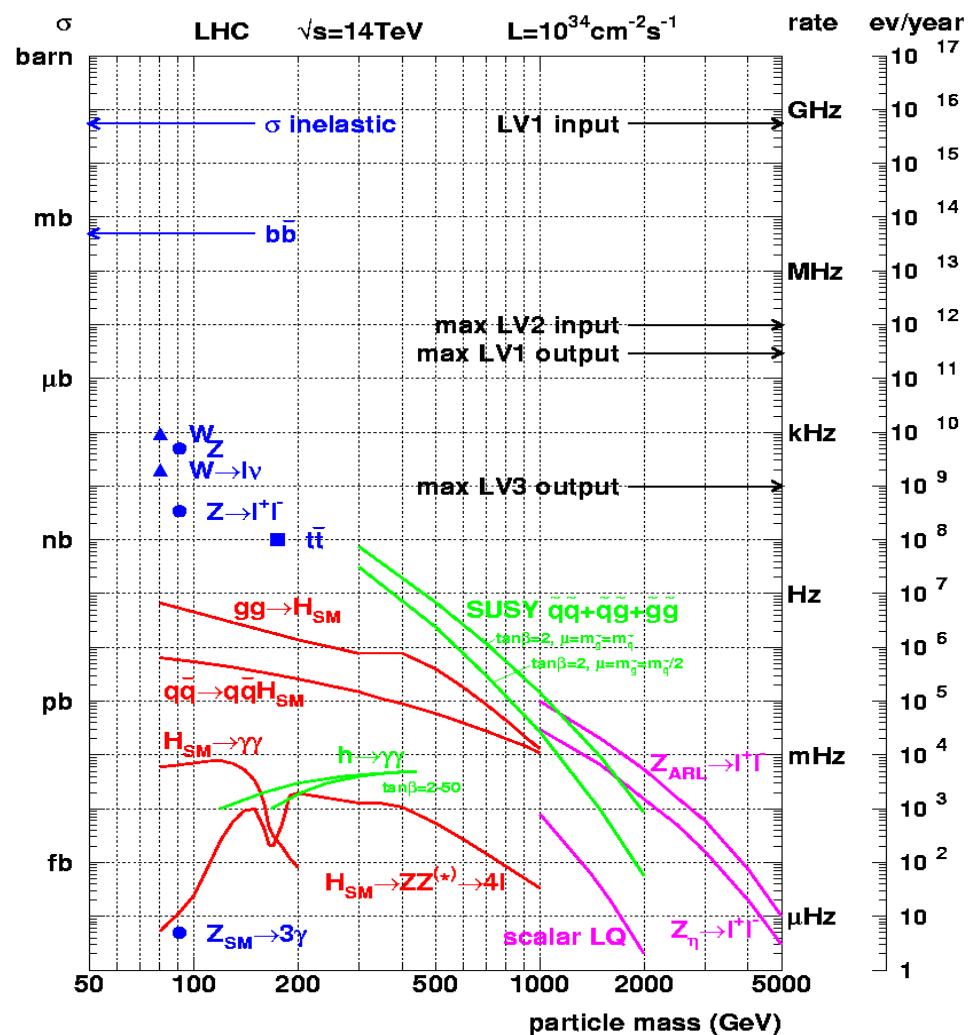


Disallowed in the Standard Model



Higgs Physics

The existence of the Higgs Boson was postulated over 40 years ago (PR.145:1156, 1966), but it has yet to be observed.

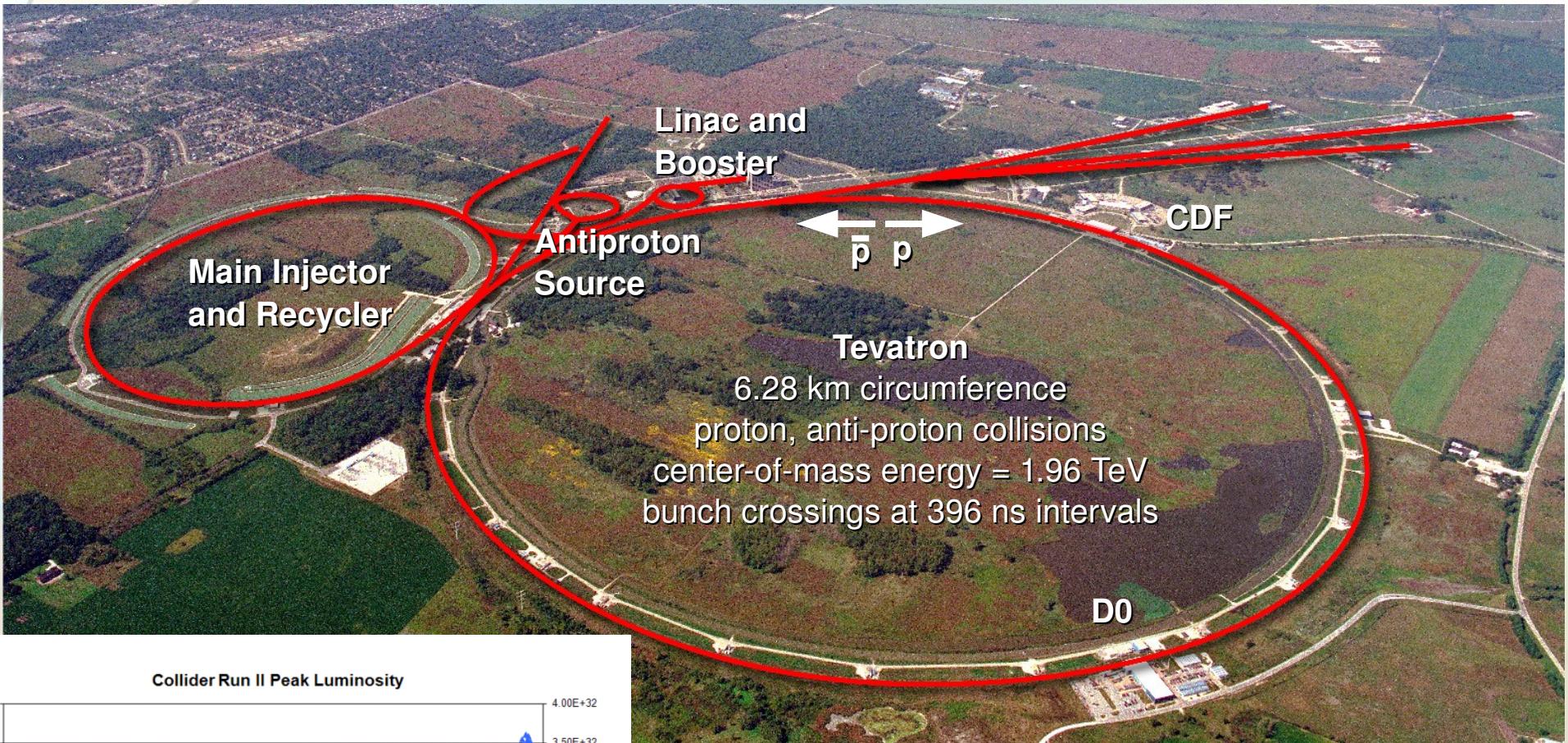


Add a self-interacting scalar field which breaks the EW symmetry to the SM
 Lagrangian: Results in masses for the W and Z bosons, and the existence of a new boson.

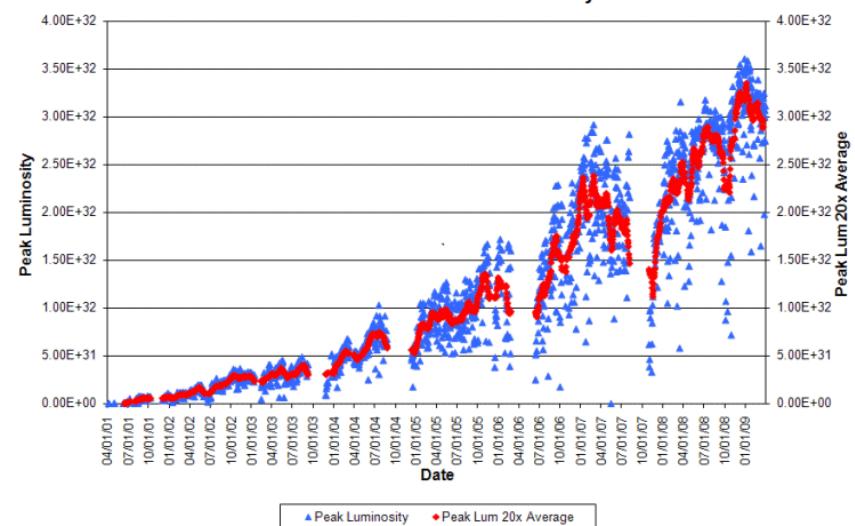
The production rates, decay rates, and couplings are all fixed: 1 free parameter, the Higgs mass!

Important to “discover” our SM backgrounds if we are to believe any claims about the Higgs.

The Tevatron

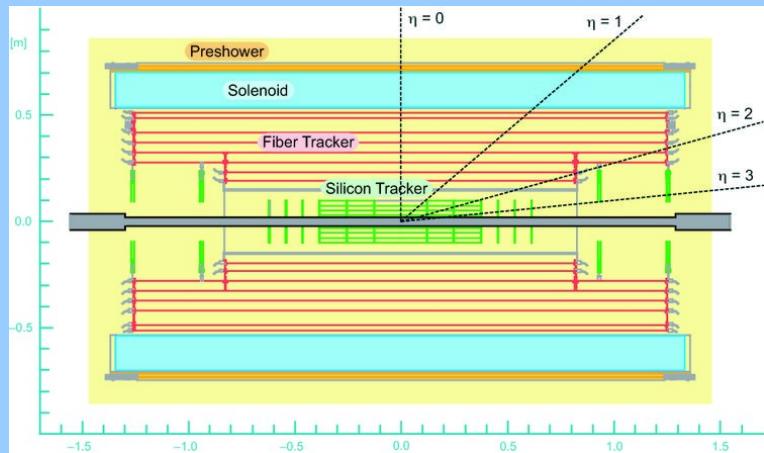


Collider Run II Peak Luminosity



The D0 Detector

Central Tracking System



1) Silicon Microstrip Tracker

$$|\eta| < 3$$

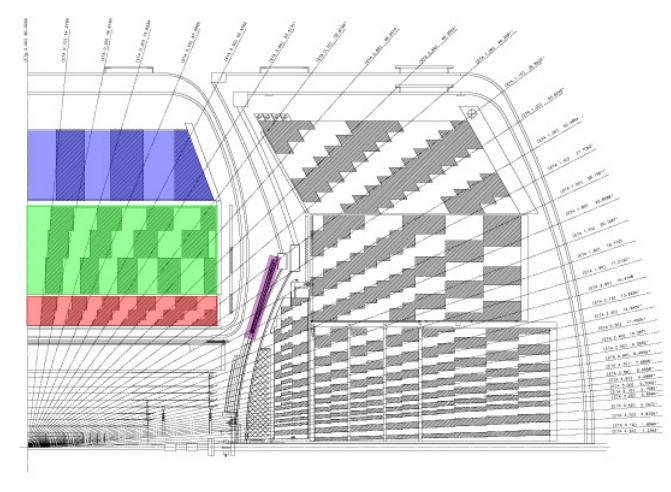
Barrel and disk silicon
semiconductors

2) Central Fiber Tracker

$$|\eta| < 1.7$$

8 layers of scintillating fiber

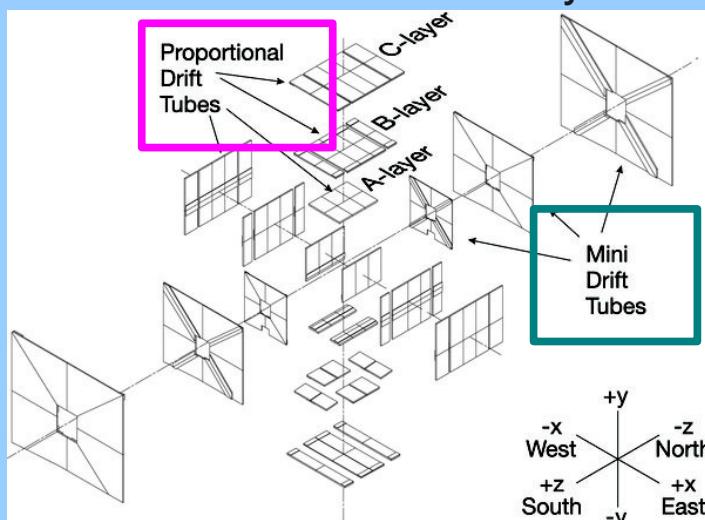
Central and End Cap Calorimeter



Full coverage: $|\eta| < 4.2$:

4 Electromagnetic Layers, 3 Fine Hadronic Layers,
1 Coarse Hadronic Layer

Muon System



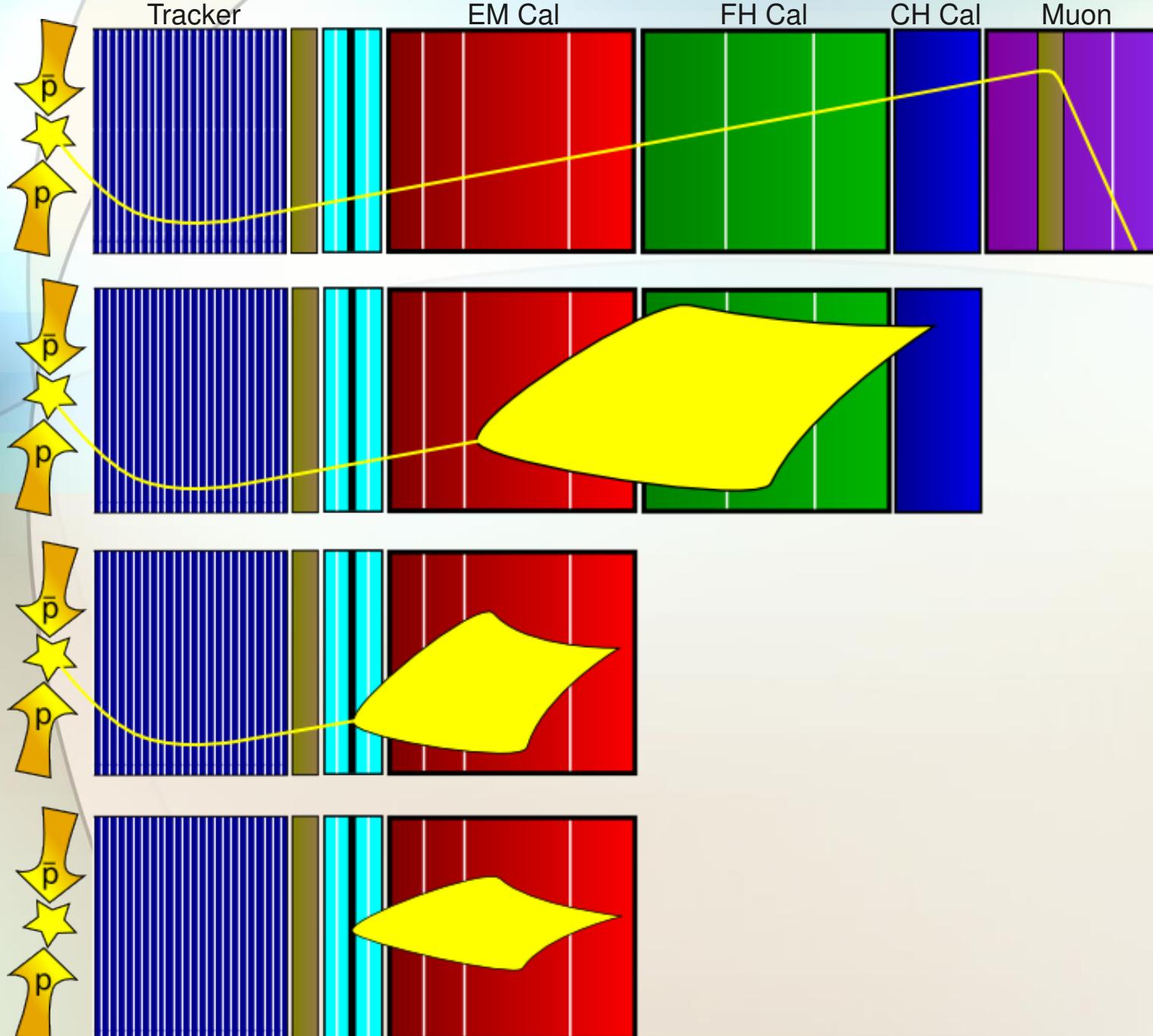
1) Central Muon
 $|\eta| < 1.0$

Proportional Drift
Tubes

2) Forward Muon
 $1.0 < |\eta| < 2.0$

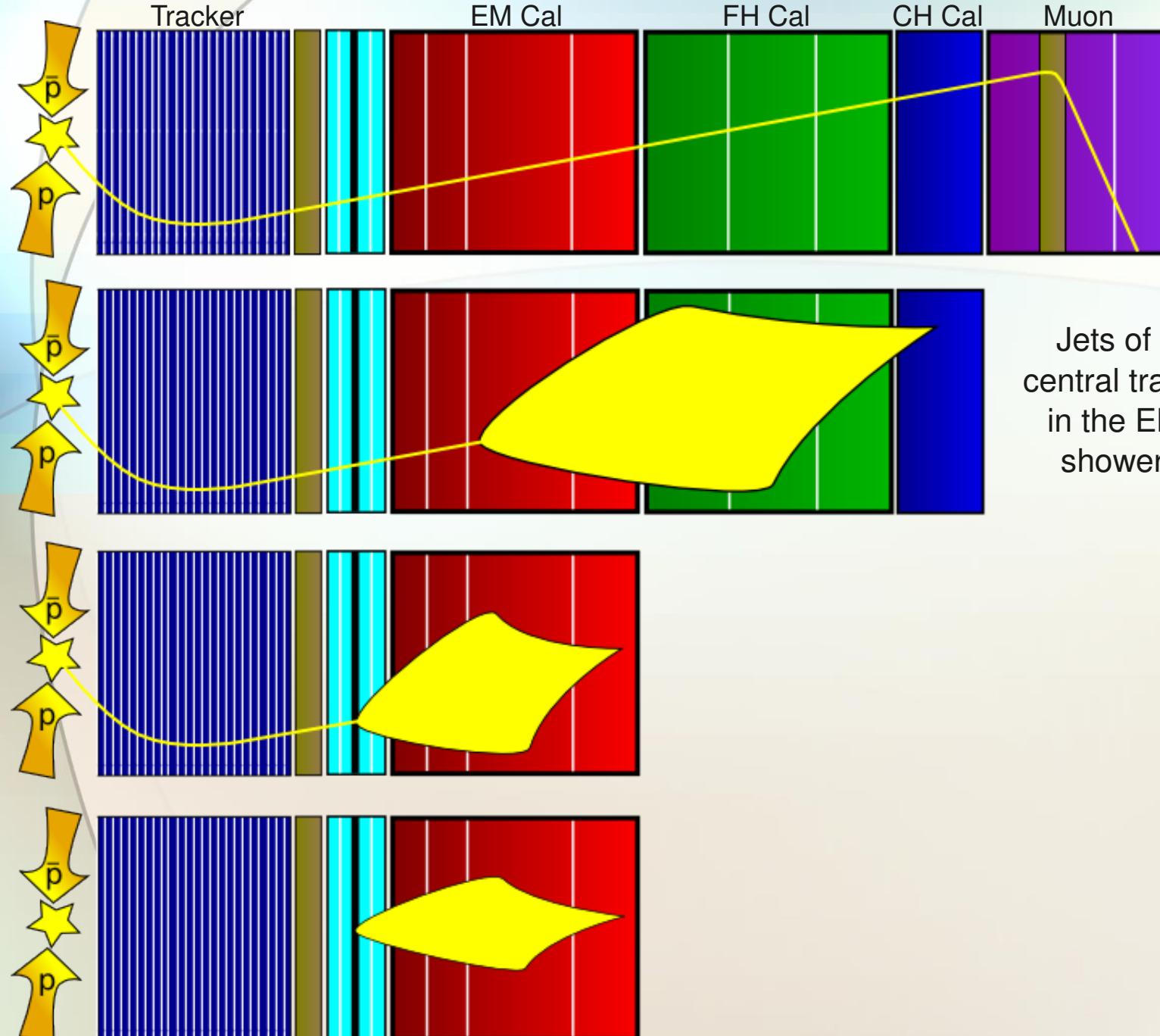
Mini Drift Tubes

Object Reconstruction : Muons



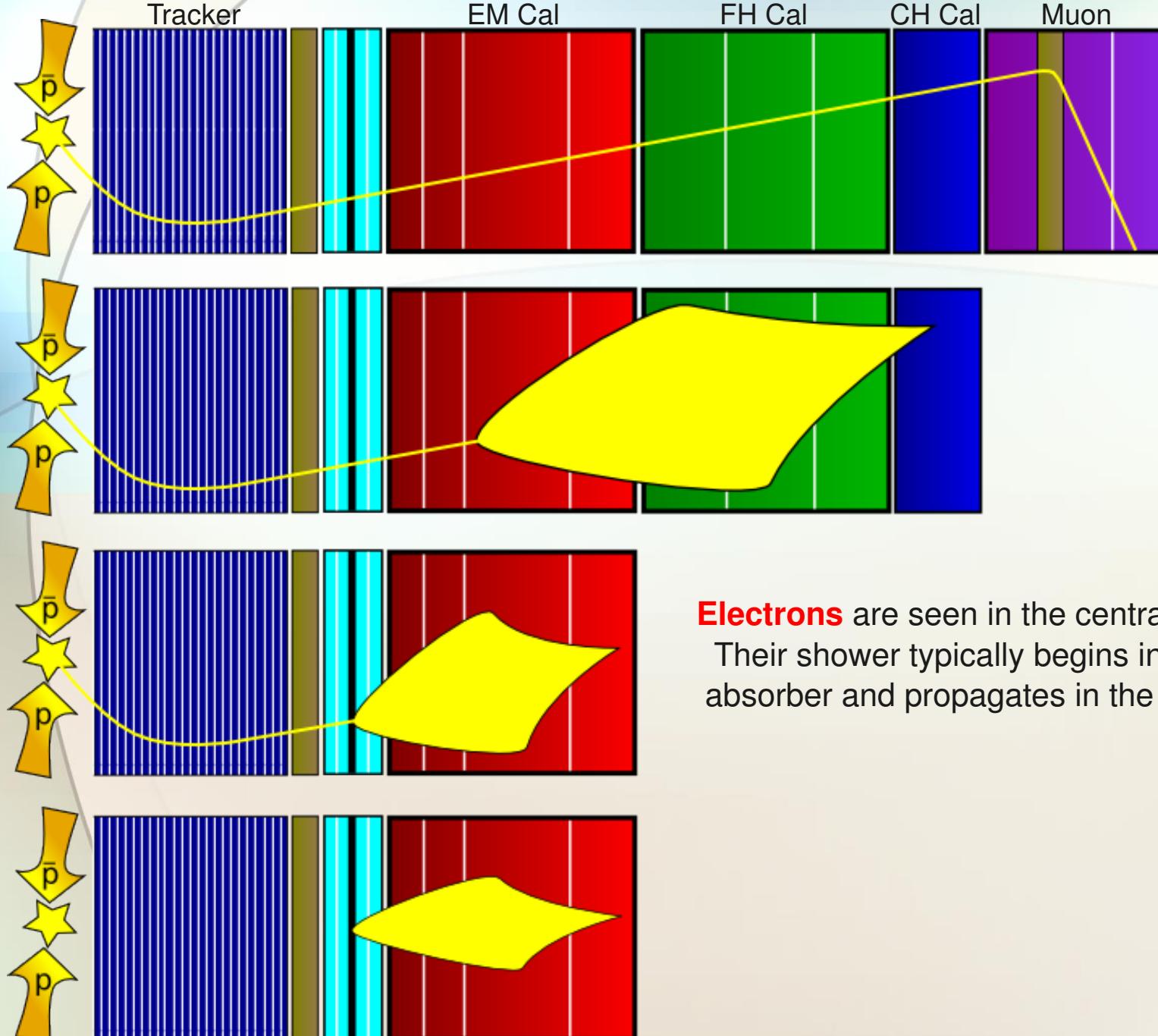
Muons produce hits in the muon detector matched to a central track. They deposit little energy in the Cal.

Object Reconstruction : Jets



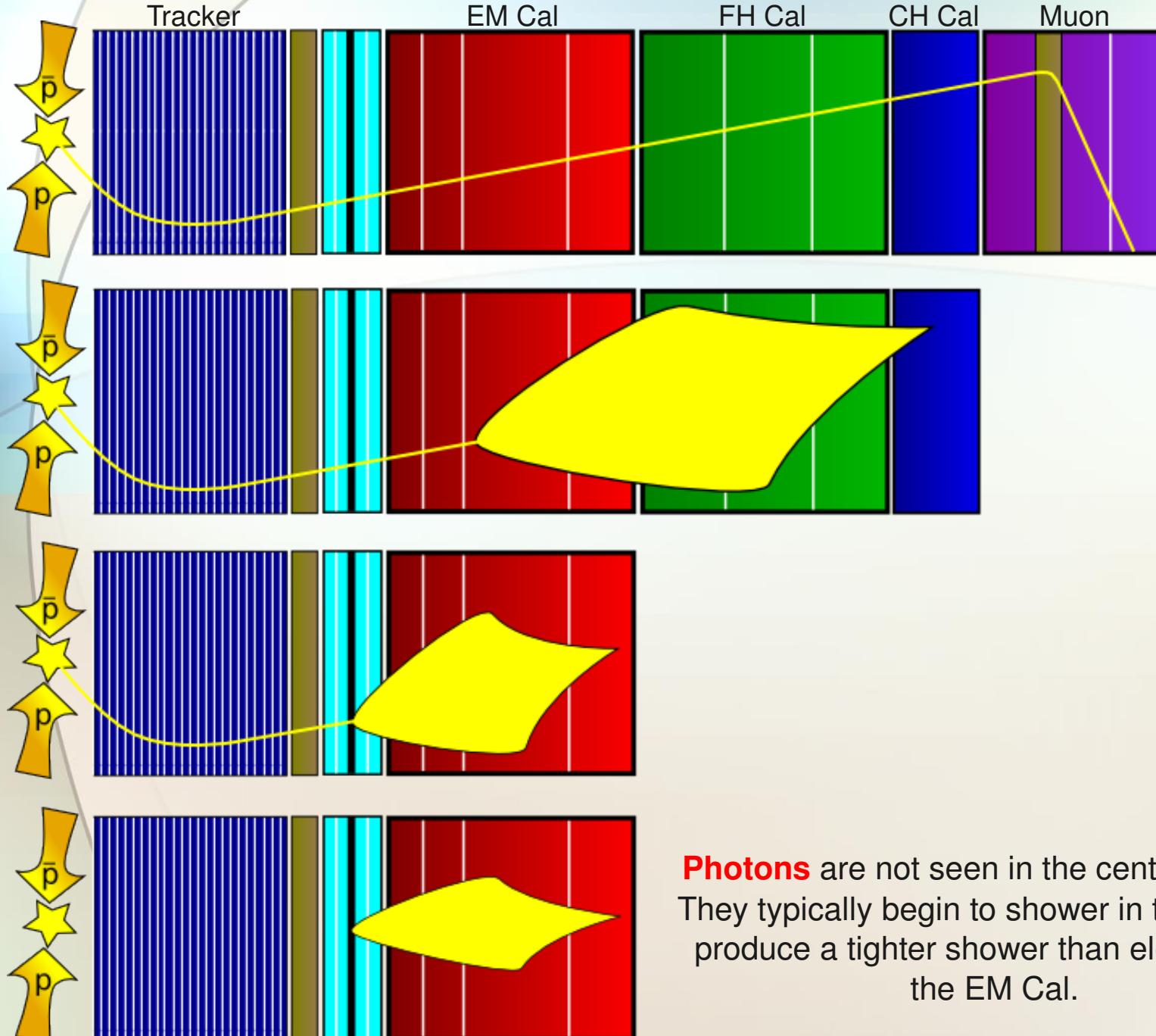
Jets of **hadrons** are seen in the central tracker, deposit some energy in the EM Cal, and produce large showers in the FH and CH Cal.

Object Reconstruction : Electrons



Electrons are seen in the central tracker.
Their shower typically begins in the PS
absorber and propagates in the EM Cal.

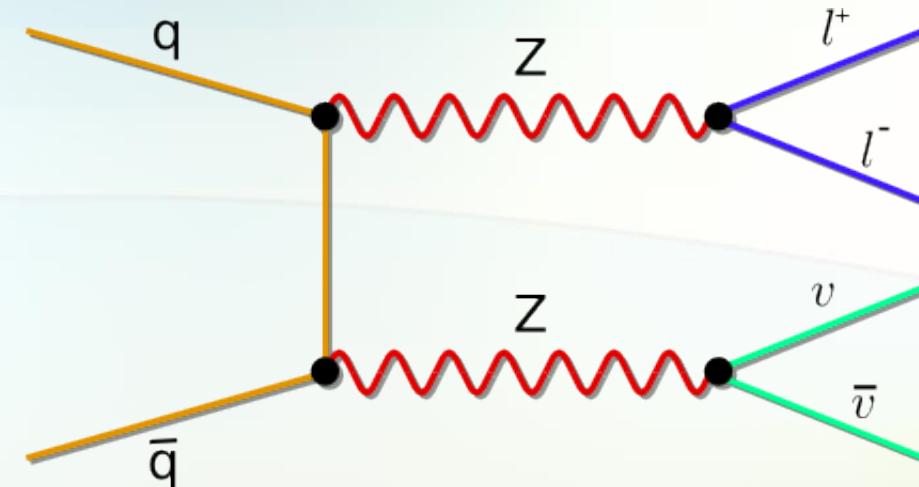
Object Reconstruction : Photons



Photons are not seen in the central tracker.
They typically begin to shower in the PS and
produce a tighter shower than electrons in
the EM Cal.

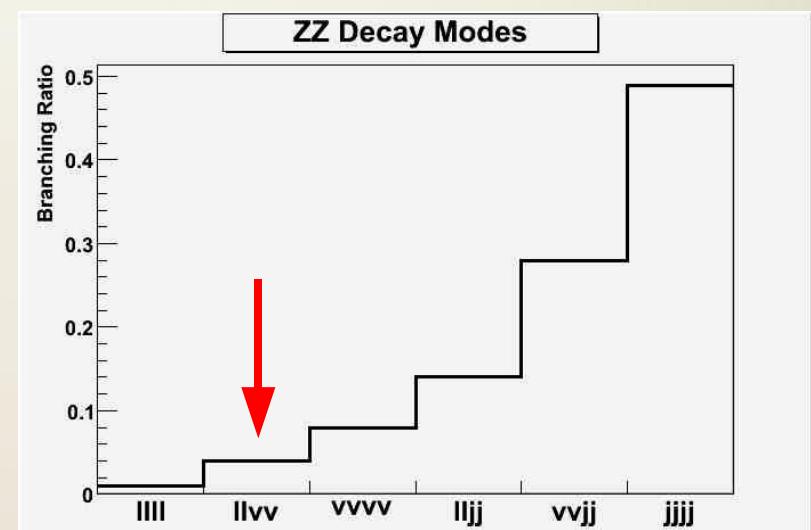
$ZZ \rightarrow llvv$: Motivation

Aside from production with a Higgs Boson, the ZZ di-boson process has the lowest cross section and **was** the last remaining unobserved di-boson process at the Tevatron.



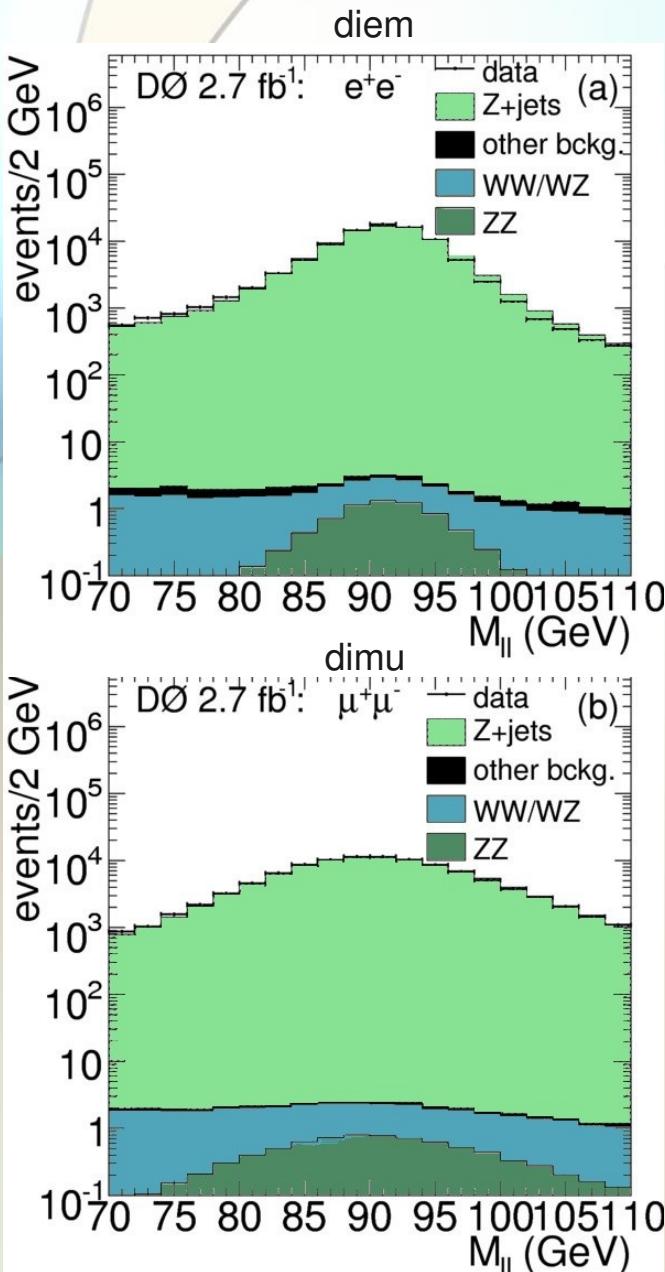
Use the fully leptonic mode $ZZ \rightarrow llvv$ (where l = electrons and muons):

- Small branching fractions w.r.t jet modes
- Larger branching fractions than the $ZZ \rightarrow llll$
- Manegeable Backgrounds
- Requires a large amount of data



Preselection

2.7 fb^{-1} : Inclusive set of electron / muon triggers
Normalize to the Z peak in Data



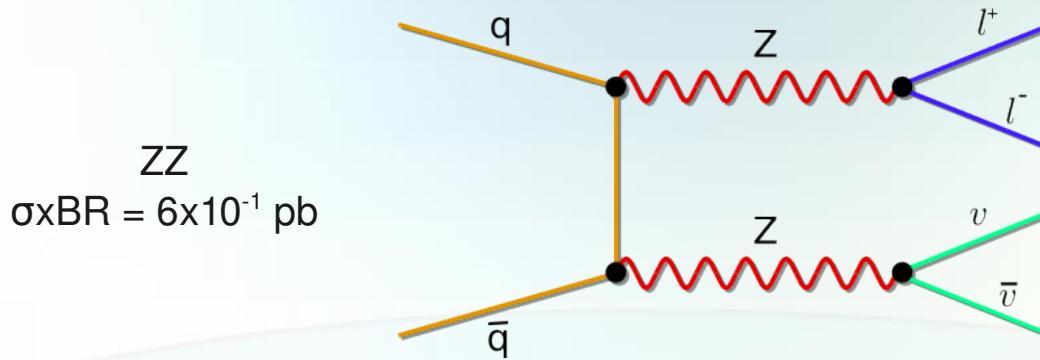
- 2 Leptons w/ $p_T > 15 \text{ GeV}$
- Tight Isolation and Shape requirements
- Electrons within the central ($|\eta| < 1.1$) or forward ($1.5 < |\eta| < 2.5$) calorimeter regions
- Muons with at least one hit in the Silicon Microstrip Tracker (SMT)

Reject events with additional low p_T or poorly reconstructed electrons, muon, taus, and isolated tracks

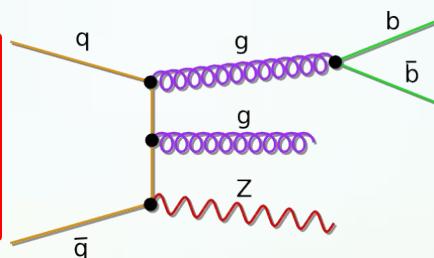
Require # of jets ≤ 2 w/ $p_T > 15 \text{ GeV}$

Di-lepton Invariant Mass $70 < M_{\parallel} < 110 \text{ GeV}$

Signal and Background Production Rates

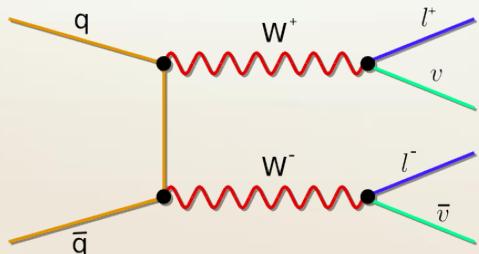
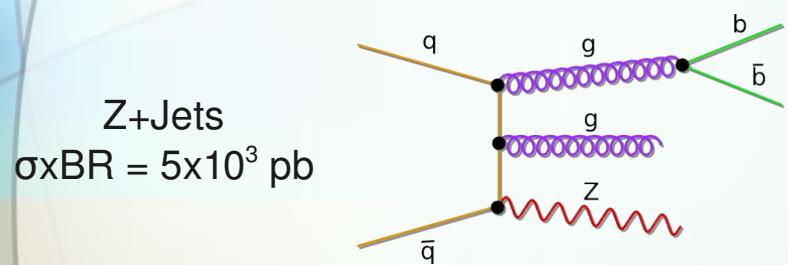
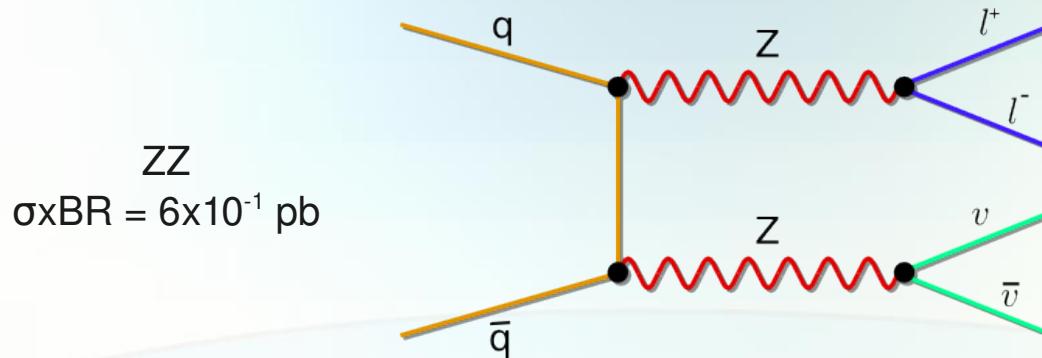


Z+Jets
 $\sigma \times BR = 5 \times 10^3 \text{ pb}$



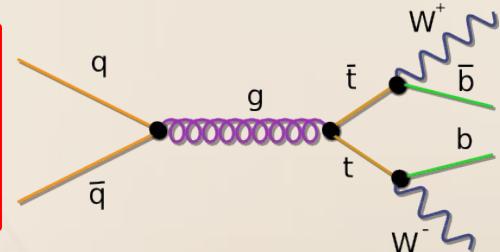
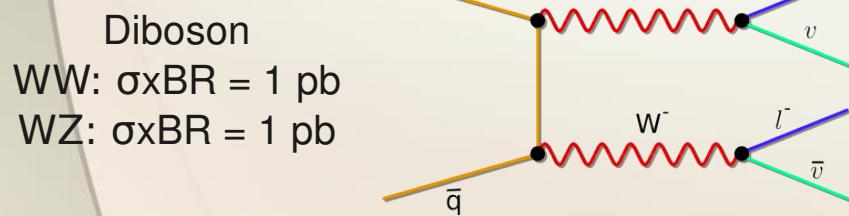
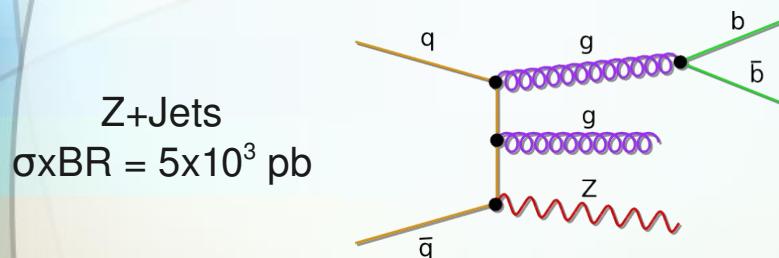
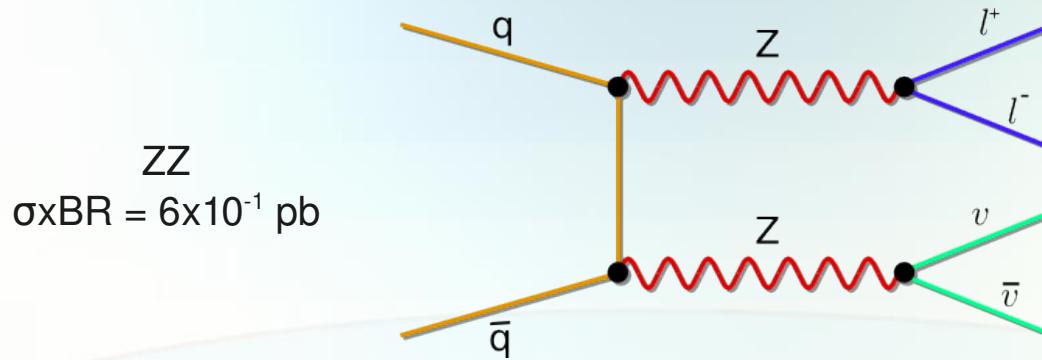
Two leptons and little (real) MET
Very large production cross section

Signal and Background Production Rates



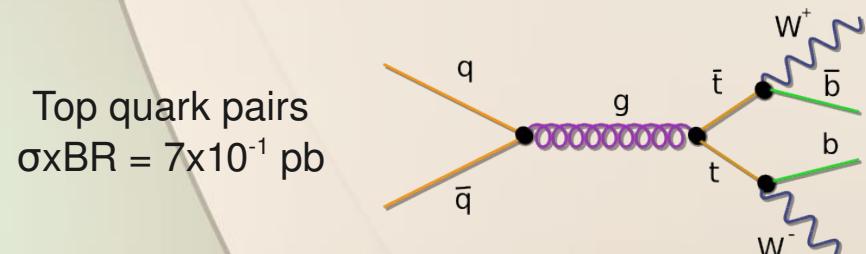
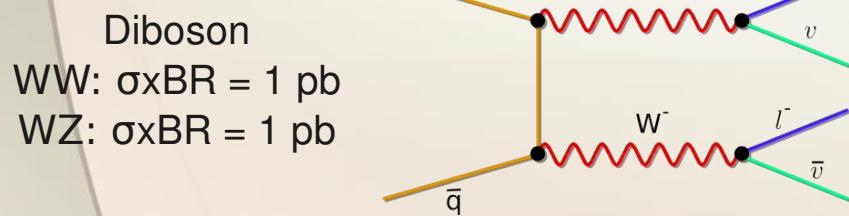
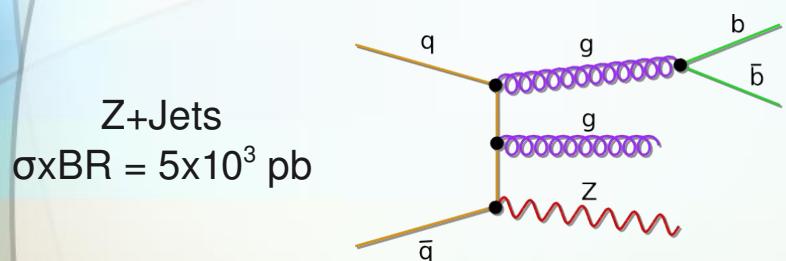
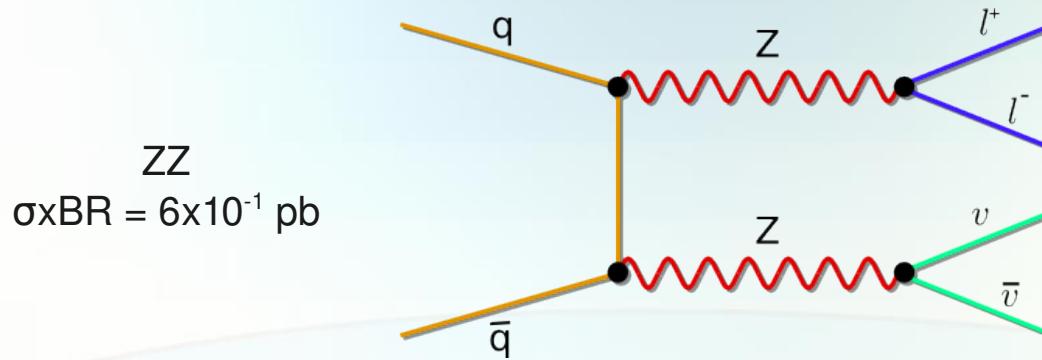
Two (three) leptons and real MET
Very signal-like signature
Small cross section, but still larger than signal

Signal and Background Production Rates



Two leptons and real MET
Dilepton mass is uniformly distributed
Many jets in the event

Signal and Background Production Rates

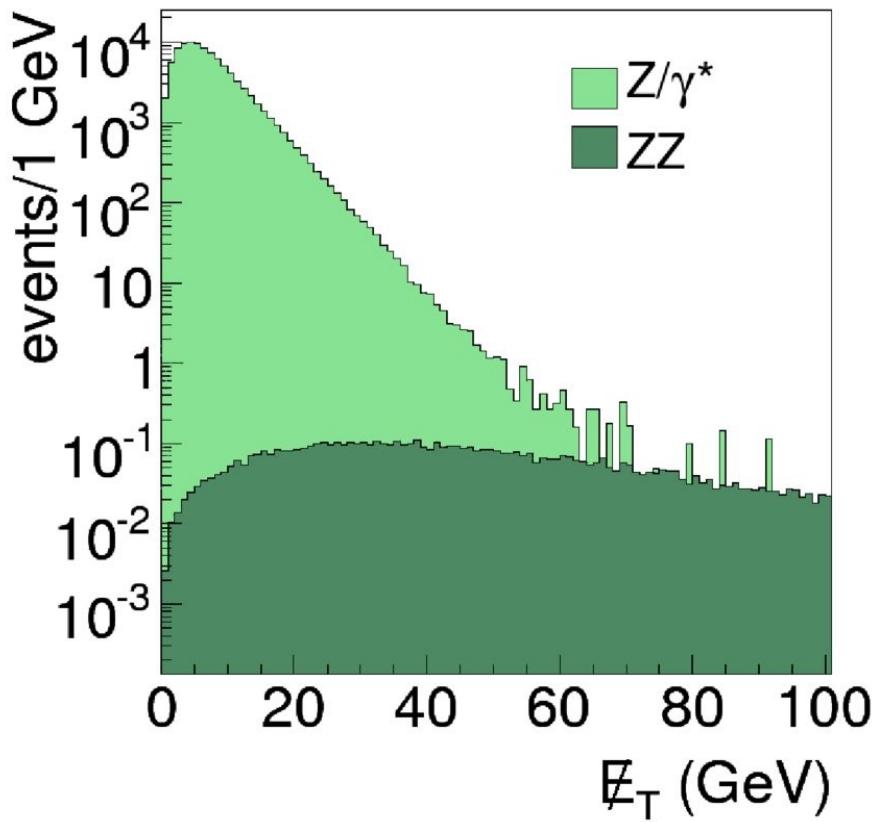


One or more faked leptons and real MET
Large production rate, but small fake rate
Predict expected yield in data
Model shapes with MC

Cut on MET?

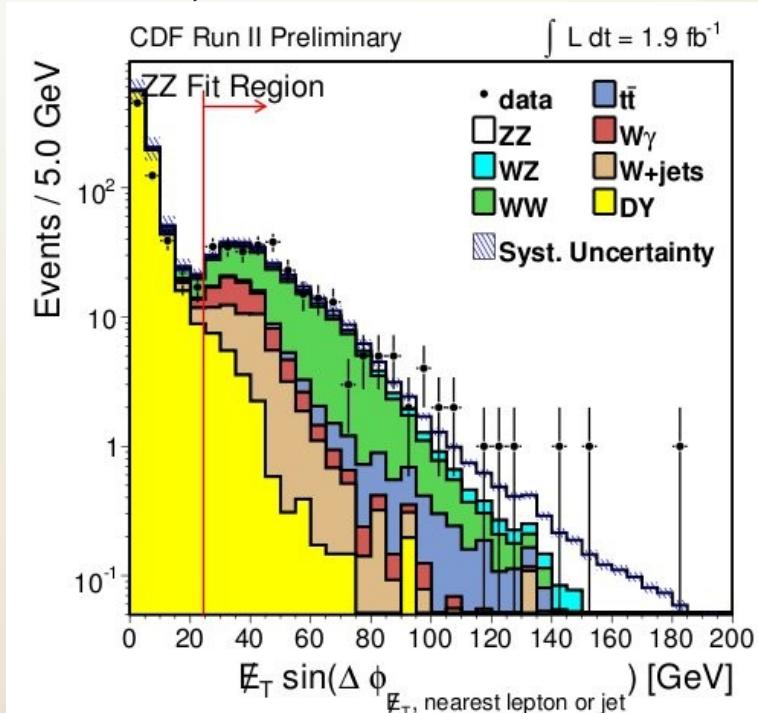
Signal with neutrinos, so expect significant MET in the event

MET for signal and the dominant background



Although the MET mis-measurement tails are small, the signal is still overwhelmed due to the substantially larger cross section of the Z/γ^* .

CDF makes a low cut on a MET variable, relies on a NN for the rest.



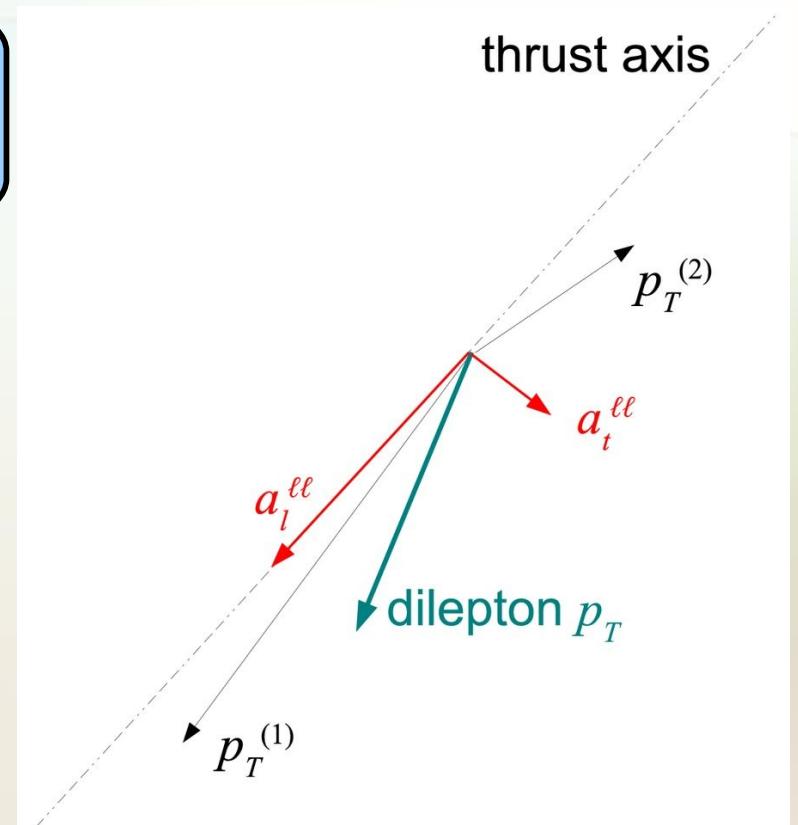
Building a Better MET Indicator

Rather than make an unbiased or accurate estimate of the MET, build a variable which is a measure of the minimum feasible MET robust against reconstruction mistakes.

- decompose di-lepton p_T in 2 components with respect to thrust axis:

- a_L : sensitive to p_T mis-measurement
- a_T : sensitive to recoil activity mis-measurement

- Correct a_L and a_T individually for:
 1. Calorimeter recoil activity (MET and Jets)
 2. p_T of recoiling tracks
 3. Lepton transverse momentum uncertainty
- Build a variable which gives more weight to a_T
 $\cancel{E}_T' = \sqrt{a_L^2 + (1.5 a_T)^2}$



Result:

- by construction all uncertainties and mis-reconstruction can ONLY reduce the value of \cancel{E}_T'

METPrime Corrections (1)

Three corrections are applied after the decomposition and before the weighted quadrature sum.

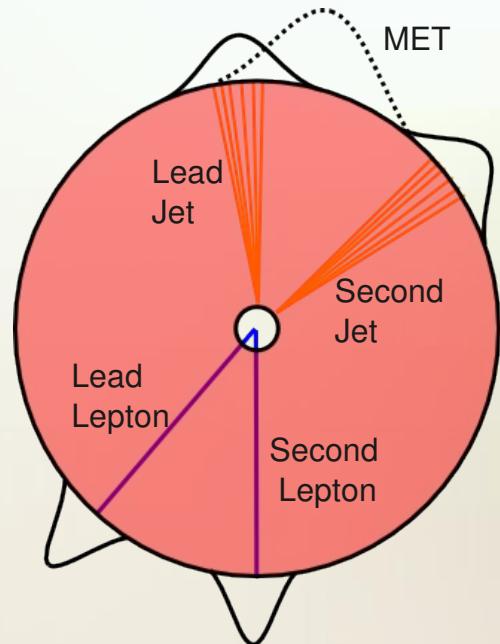
1. Calorimeter Recoil Activity

Determine a correction based on the vector sum of jet E_T or the uncorrected missing transverse energy, picking the one with the largest magnitude.

a_L and a_T decomposition:

$$\delta a_t^{cal} = 2 \times \min(\sum \vec{E}_T^{jets} \cdot \hat{a}_t, \vec{E}_T \cdot \hat{a}_t, 0)$$

$$\delta a_l^{cal} = 2 \times \min(\sum \vec{E}_T^{jets} \cdot \hat{a}_l, \vec{E}_T \cdot \hat{a}_l, 0)$$



A jet is only included in the sum if its p_T is pointing in the hemisphere opposite the dilepton pair.

METPrime Corrections (2)

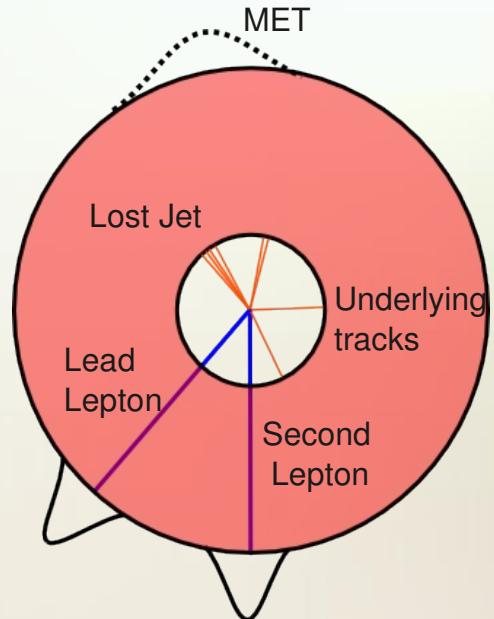
Three corrections are applied after the decomposition and before the weighted quadrature sum.

2. Recoiling Tracks

Account for tracks which are well separated from the candidate leptons and calorimeter jets.

$$\delta a_t^{trk} = (\sum \vec{p}_T^{t\,jet}) \cdot \hat{a}_t$$

$$\delta a_l^{trk} = (\sum \vec{p}_T^{t\,jet}) \cdot \hat{a}_l$$



Build jets of tracks with cone size 0.5:

Accounts for events in which the recoil activity is not observed in the calorimeter as jets. Track-jets as well are only included in the sum if their p_T is in the direction opposite the dilepton pair.

METPrime Corrections (3)

Three corrections are applied after the decomposition and before the weighted quadrature sum.

3. Lepton p_T Uncertainty

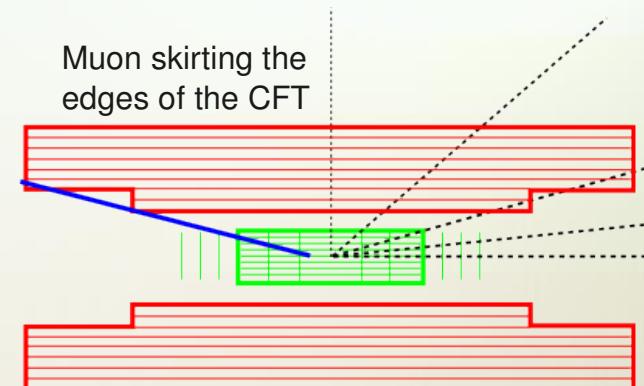
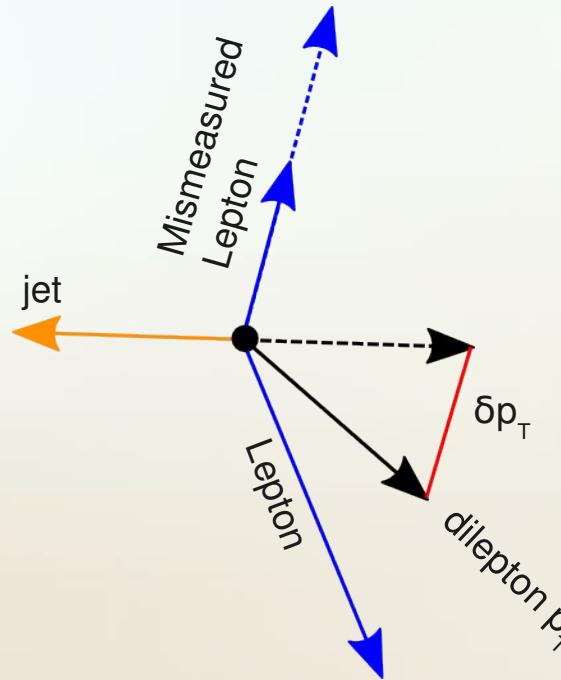
Compute a correction term accounting for lepton transverse momentum measurement uncertainties.

$$\vec{p}_T' = (1 - \sigma) \vec{p}_T, \text{ etc...}$$

$$a_t^{\ell\ell'} = \vec{p}_T^{\ell\ell'} \cdot \hat{a}_t'$$

$$\delta a_t^{\ell\ell} = a_t^{\ell\ell'} - a_t^{\ell\ell}$$

$$\delta a_l^{\ell\ell} = (-\sigma_1 \vec{p}_T^{(1)} + \sigma_2 \vec{p}_T^{(2)}) \cdot \hat{a}_l$$



Fluctuate the lepton p_T by one standard deviation, minimizing the dilepton projections along a_T and a_L

$$\hat{a}_t = \vec{t}_\perp / |t| \quad \hat{a}_l = \vec{t}_\parallel / |t| \quad 21$$

METPrime Corrections (3)

Three corrections are applied after the decomposition and before the weighted quadrature sum.

3. Lepton p_T Uncertainty

Compute a correction term accounting for lepton transverse momentum measurement uncertainty

$$a_t = a_t^{\ell\ell} + \delta a_t^{cal} + k' \times \delta a_t^{trk} + k \times \delta a_t^{\ell\ell}$$

$$a_l = a_l^{\ell\ell} + \delta a_l^{cal} + k' \times \delta a_l^{trk} + k \times \delta a_l^{\ell\ell}$$

$$a'_t = \max(a_t, 0) \quad a'_l = \max(a_l, 0)$$

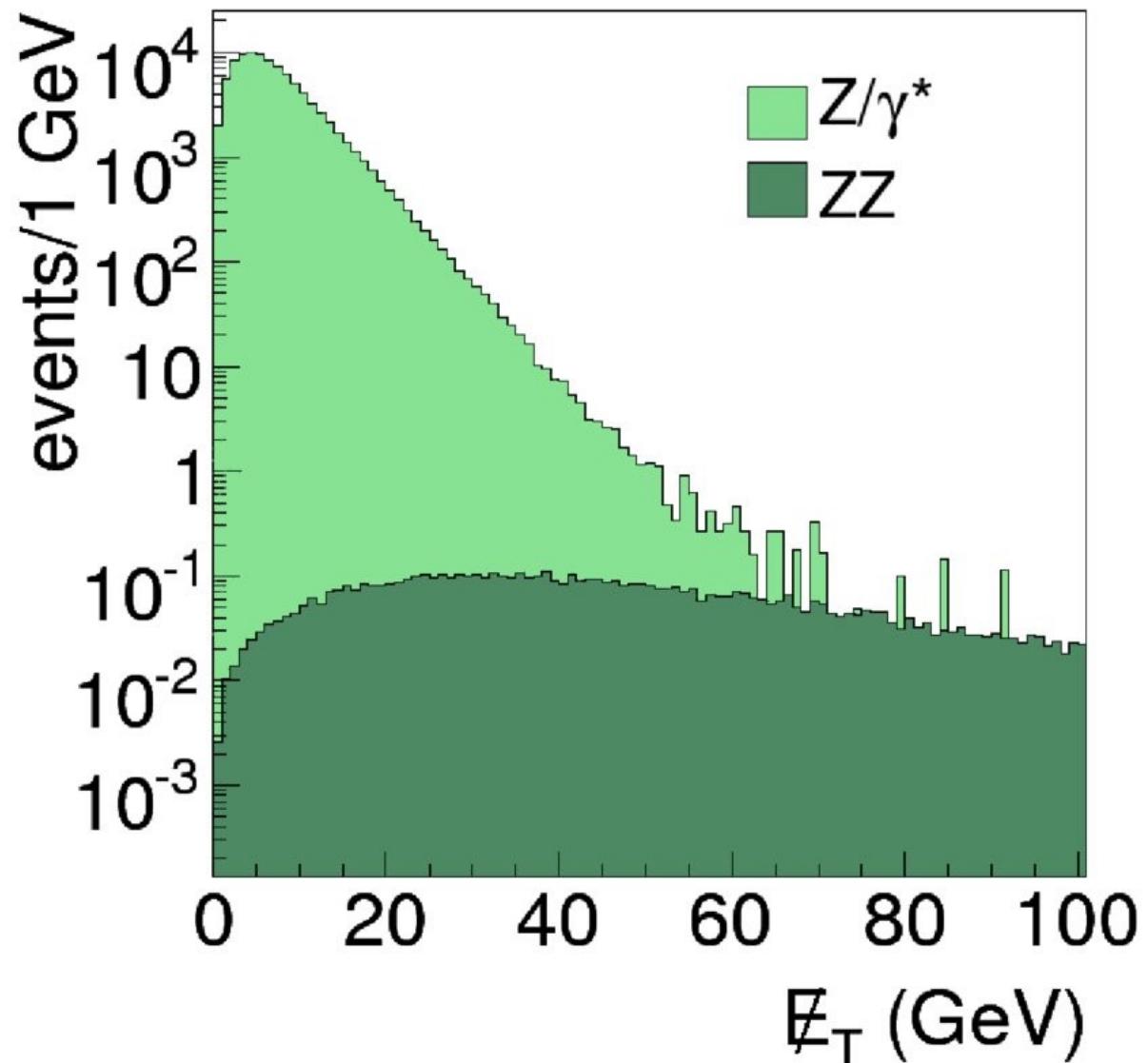
$$E_T' = \sqrt{a_l'^2 + (1.5a_t')^2}$$



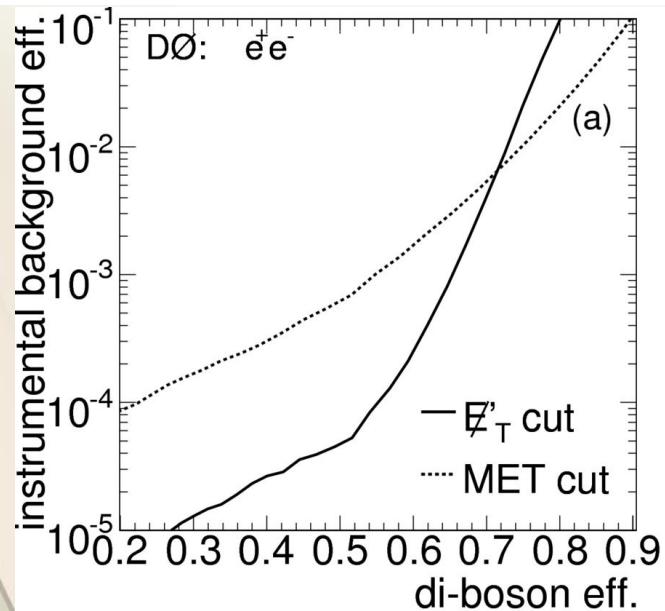
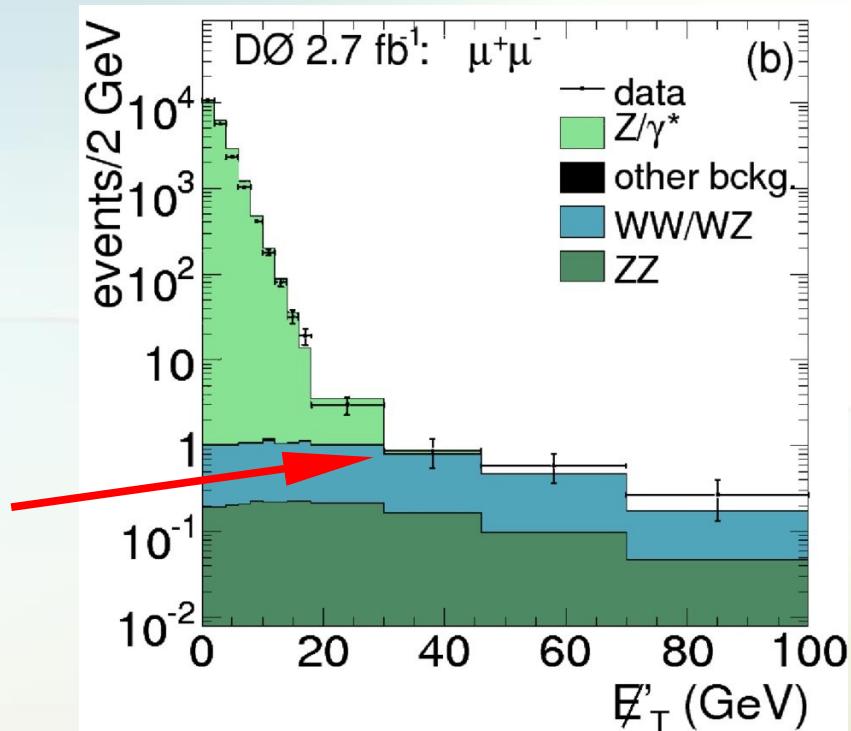
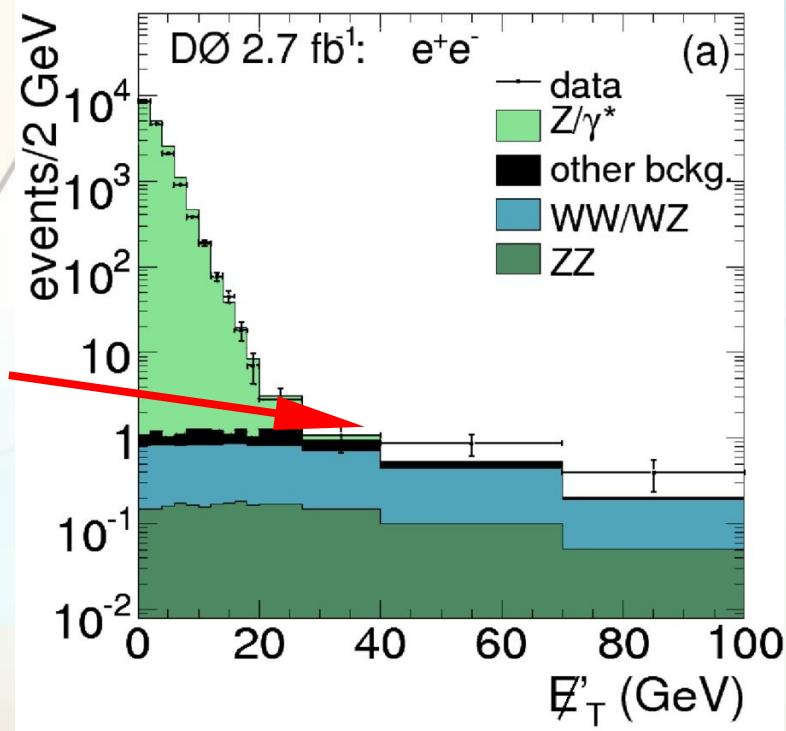
Fluctuate the lepton p_T by one standard deviation, minimizing the dilepton projections along a_T and a_L

$$\hat{a}_t = \vec{t}_\perp / |t| \quad \hat{a}_l = \vec{t}_\parallel / |t| \quad 22$$

What's The Pay Off?



Instrumental Background Rejection



Yields after the E'_T cut:

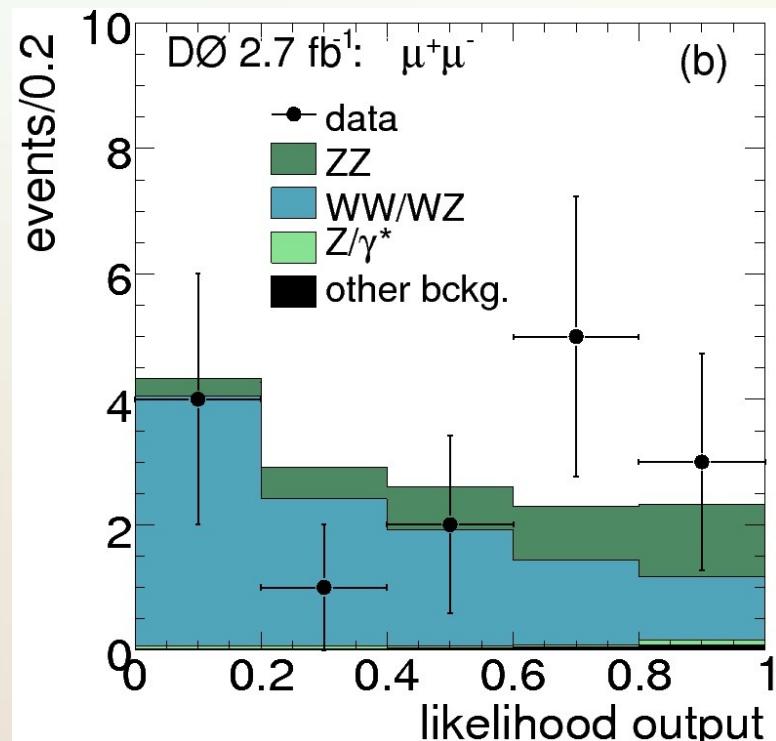
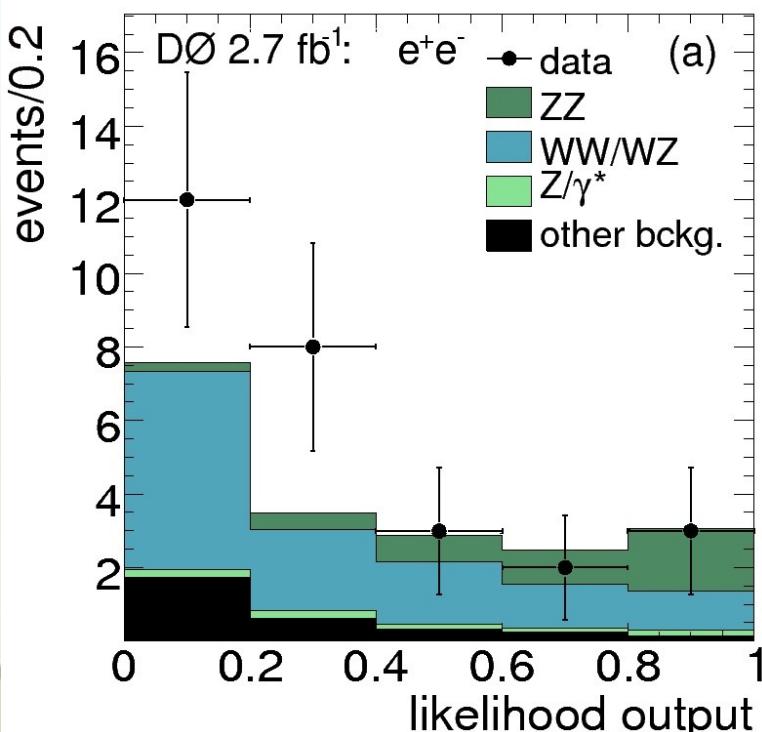
Sample	diem	dimu
Z->ll	0.5 ± 0.2	0.1 ± 0.1
ZZ->llvv	4.03	3.39
Tot Bckg	15.6 ± 0.4	10.9 ± 0.3
Bkgd + Signal	19.6 ± 0.4	14.3 ± 0.3
Data	28	15

Likelihood Method

Remaining physics backgrounds are further separated from the signal using a likelihood method.

Calculate and fit S/(S+B) per bin for 4 distributions:

$$f(x_1, x_2, \dots) = f(x_1) * f(x_2) * \dots$$



Likelihood Variables:

- Di-lepton mass (diem)
- Chi2 probability (dimu)
- Leading lepton p_T
- $\Delta\Phi(\text{lead lep, di-lep})$
- $\cos(\theta^*)$

Systematic Uncertainties

Consider two types of systematics:

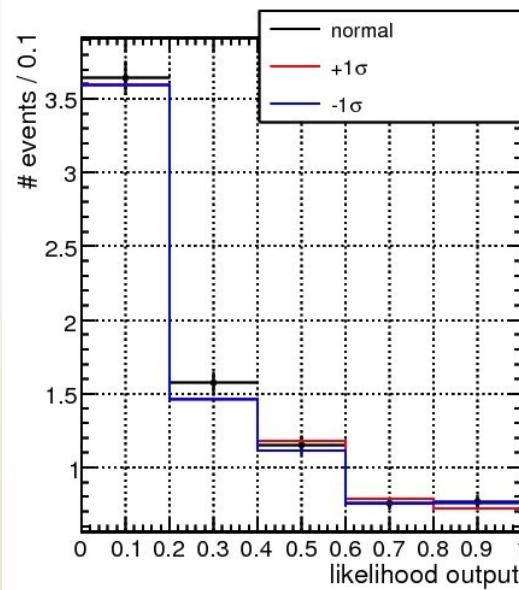
Normalization – Uncertainties which affect the overall normalization

Shape – Uncertainties which have an intrinsic shape (eg. vary with pT), or pick up a shape when convoluted by the multivariate classifier (eg. due to variable correlations).

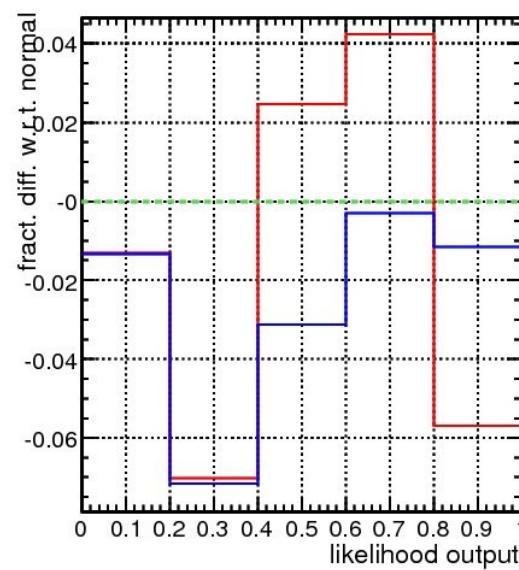
Considered 17 sources of systematic error

Heavy hitting systematics:

- W+jets normalization: ~30% for dijet
- Jet Energy Scale: Up to 50% in the METPrime tail.
- WW/WZ cross section: 7% for both



Absolute Variation



Fraction Variation

Significance Calculation

Calculate the measurement significance using a semi-frequentist approach:

Consider two hypotheses: (1) Background Only and (2) Signal + Background

Likelihood that (1) and (2) agree with the data

Generate pseudo-experiments from random Poisson trials with means from (1) and (2) (this is the frequentist part)

Systematics are treated as Gaussian uncertainties on the # of expected events, allowing the means to vary for each pseudo-experiment (this is the “semi” part)

Calculate a negative log likelihood ratio for each pseudo experiment and for the data

→ The integral of (1) below the observed (expected) LLR gives p-value – the probability of the hypothesis fluctuating to give an LLR bigger than the one observed.

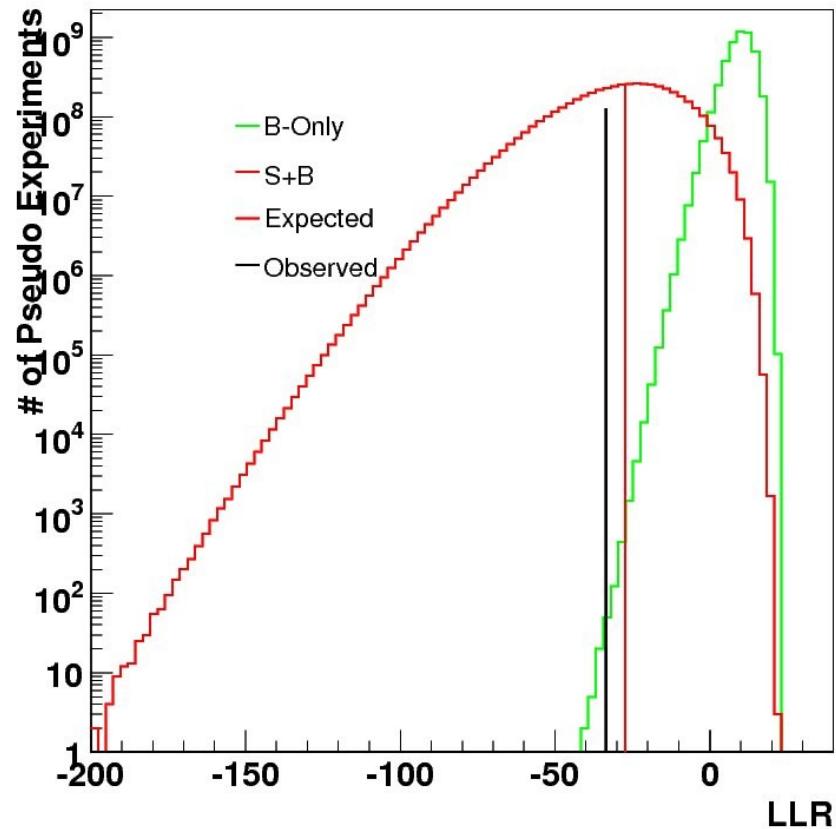
Additionally: Fit the signal and background distributions by minimizing the Poisson Chi2 within the uncertainties.

$$\chi^2 = -2\ln L = 2 \sum_{i=0}^{N_{bins}} (\hat{B}_i - D_i) - D_i \ln \left(\frac{\hat{B}_i}{D_i} \right) + \sum_{k=0}^{N_{syst}} S_k^2$$
$$\hat{B}_i \rightarrow B_i \prod_{k=0}^{N_{syst}} (1 + \sigma_i^k S_k)$$

B_i = nominally predicted bin content
 σ_i^k = fractional uncertainty
 S_k = N sigma deviation from nominal

$ZZ \rightarrow (llvv, llll')$ Combined Result

An orthogonal search has been performed at D0 in the ZZ to four charged leptons channel in which three candidate events have been found.



The combined significance is determined by calculating the probability that the background fluctuate up to our observed values from 3×10^9 pseudo-experiments.

First observation at a hadron collider:

$ZZ \rightarrow llvv$: 2.0σ exp 2.6σ obs

$ZZ \rightarrow llll'$: 4.2σ exp 5.0σ obs

Combined: 4.8σ exp 5.7σ obs

$$\sigma(ZZ) = 1.60 \pm 0.63 \text{ (stat.)}^{+0.16}_{-0.17} \text{ (syst.) pb}$$

Predicted Standard Model
cross section: 1.4 ± 0.1 pb

$ZZ \rightarrow llvv$ published in PRD 78, 072002 (2008)

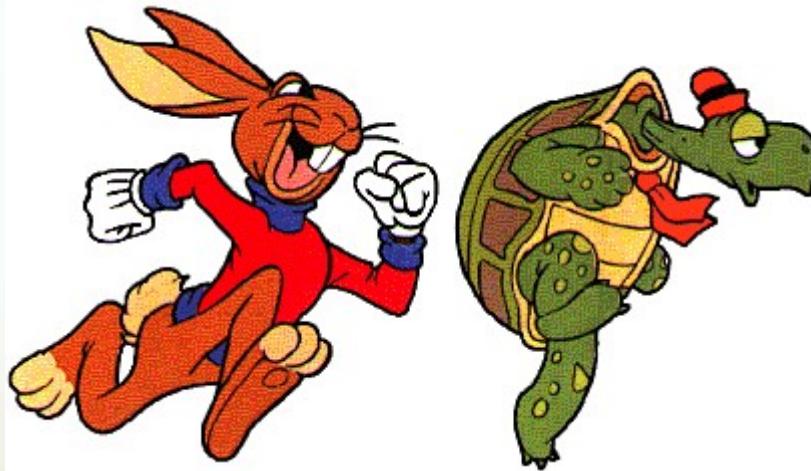
$ZZ \rightarrow llll'$ and combination published in PRL 101, 17183 (2008)

vertical red line: expected LLR from pseudo-experiments

vertical black line: value observed from data

Let's Take a Breather

We've now found all of the diboson processes at the Tevatron.



Let's talk a bit about looking for the Higgs.

Standard Model Higgs Production

Gluon fusion

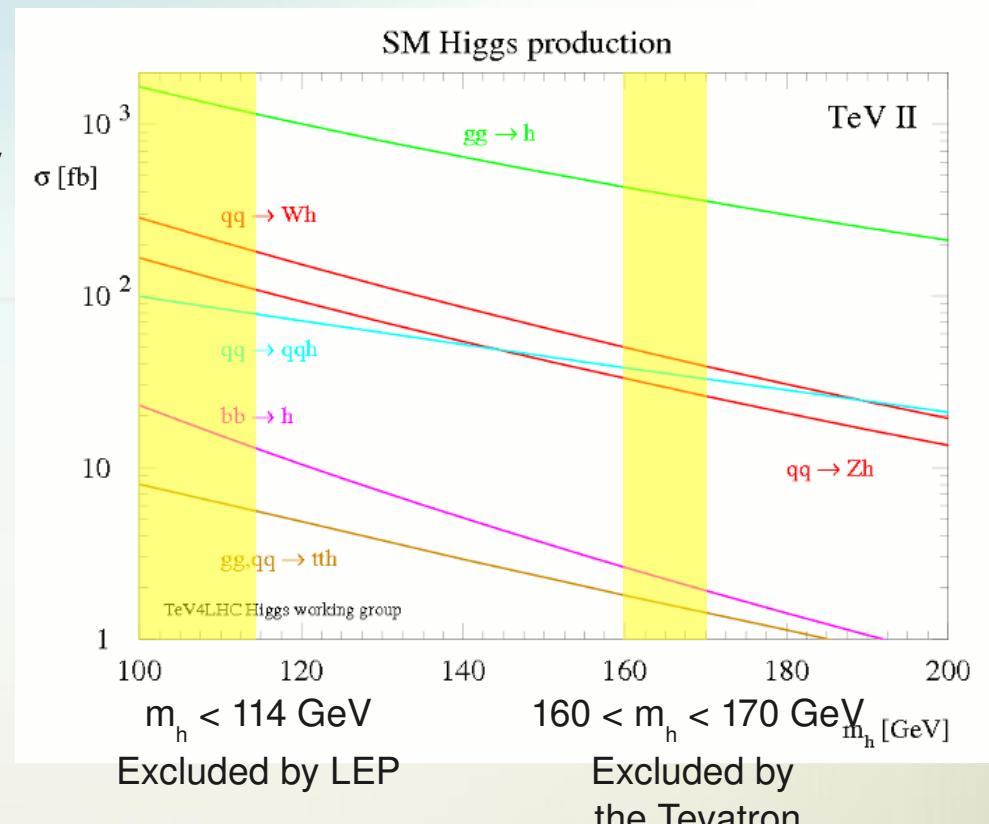
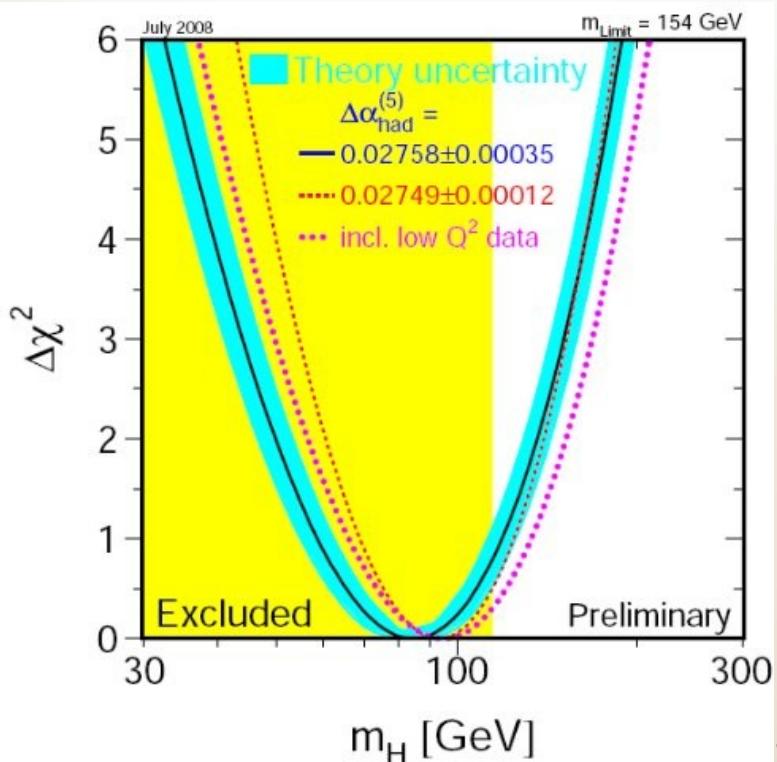
- dominant production mechanism at Hadron colliders
- suffers from large backgrounds in the bb decay mode (multijet)
- very useful at $m_H > 135$ GeV ($H \rightarrow WW$)

Vector Boson Fusion

- significant contributions at high mass

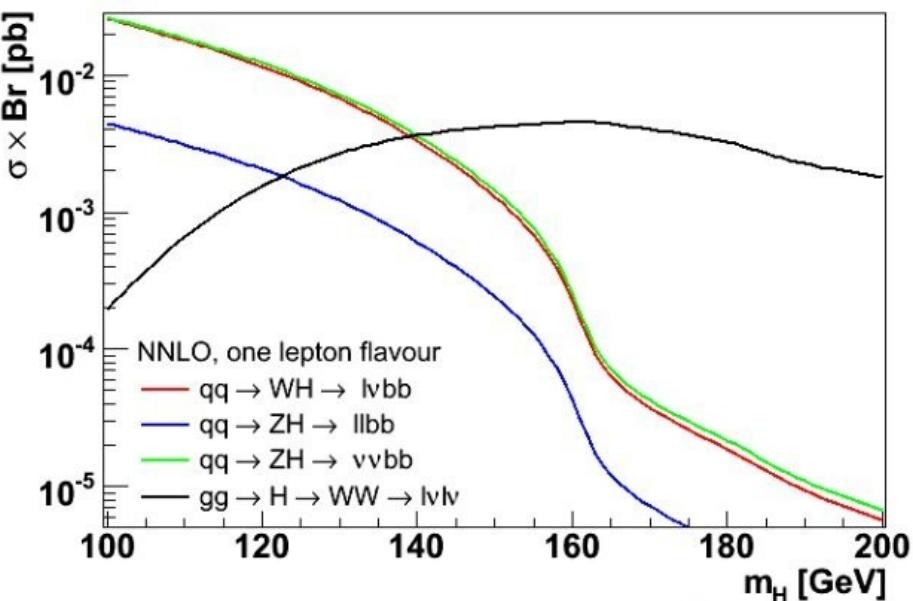
Associated production with a W/Z

- order of magnitude smaller cross section
- substantially cleaner
- non-resonant mass spectrum from background



Data favors a low mass Higgs which would decay preferentially to a pair of b quarks.

Search Strategy



0 lepton: $ZH \rightarrow \nu\nu bb$

1 lepton: $WH \rightarrow l\nu bb$

2 leptons: $ZH \rightarrow ll bb$

Multijet
Background
Signal

Look for events with two leptons ($\mu\mu$, $\mu+\text{trk}$, ee , $e+\text{ICR}$) and little mE_T

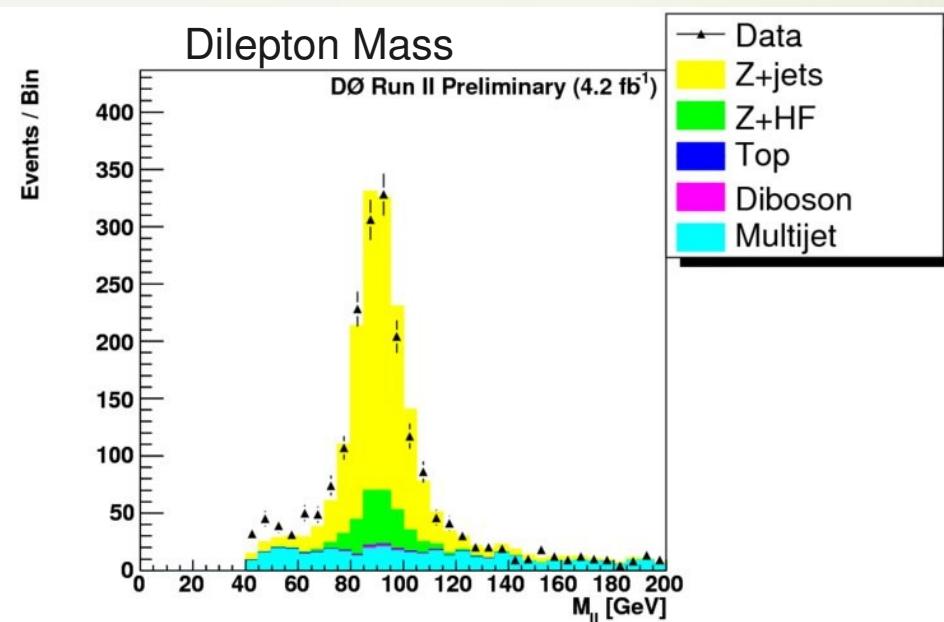
Using 4.2 fb^{-1} of data, select events passing any and all triggers

$\mu+\text{trk}$ selection requirements:

$\mu p_T > 15 \text{ GeV}$	tightly isolated
$\text{trk } p_T > 20 \text{ GeV}$	opposite charge
>= 2 Jets	

$\mu+\text{trk}$ yields ~1/5 that of the $\mu\mu$ search channel

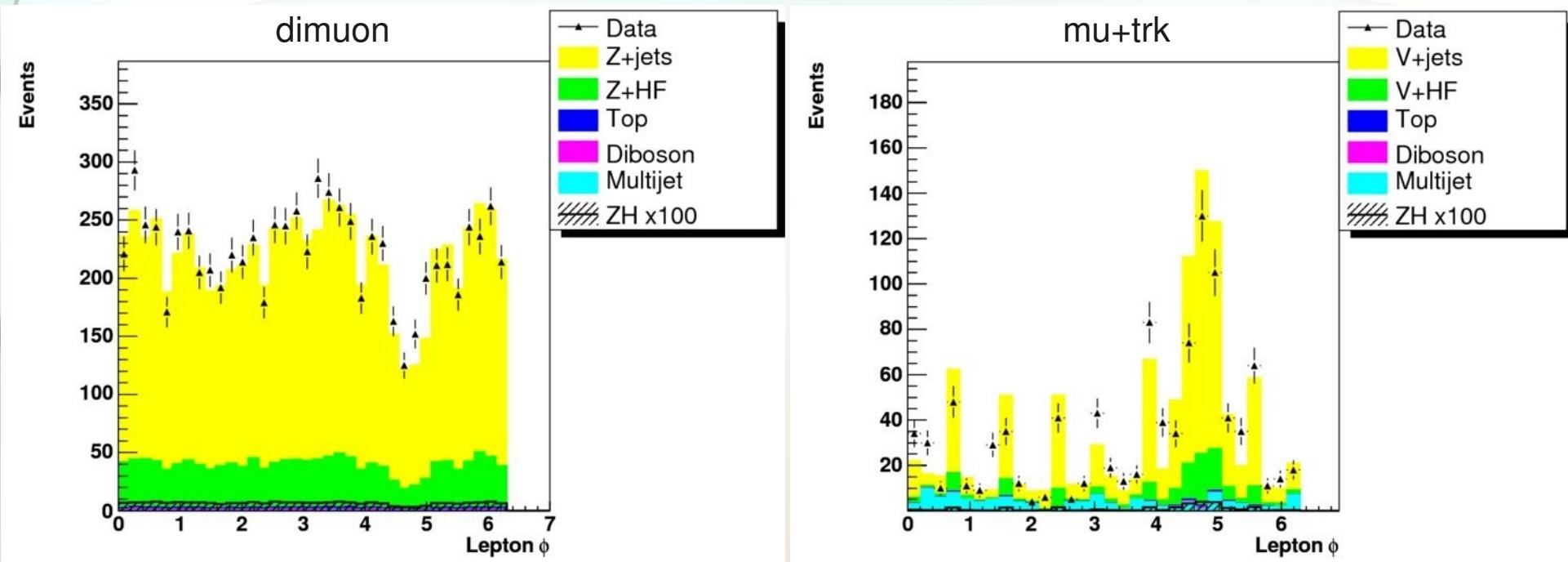
Signal / Background : $\sim 2.5 \times 10^{-4}$



Expanded Muon Coverage

Three common causes for lost muons:

- 1) the **phi hole** (due to the support structure)
- 2) the **octant gaps** (due to geometry and read-out electronics).
- 3) **very forward** muons (outside of the detector coverage, not recovered here)



Muon identification is estimated to be $\sim 80\%$ efficient

A 15% gain in acceptance represents a large fraction of the lost muons
(plus some amount of fakes)

B-Tagging

D0 selects b jets using a **Neural Net tagger**:

Combination of secondary vertex and distance of closest approach variables

Require either:

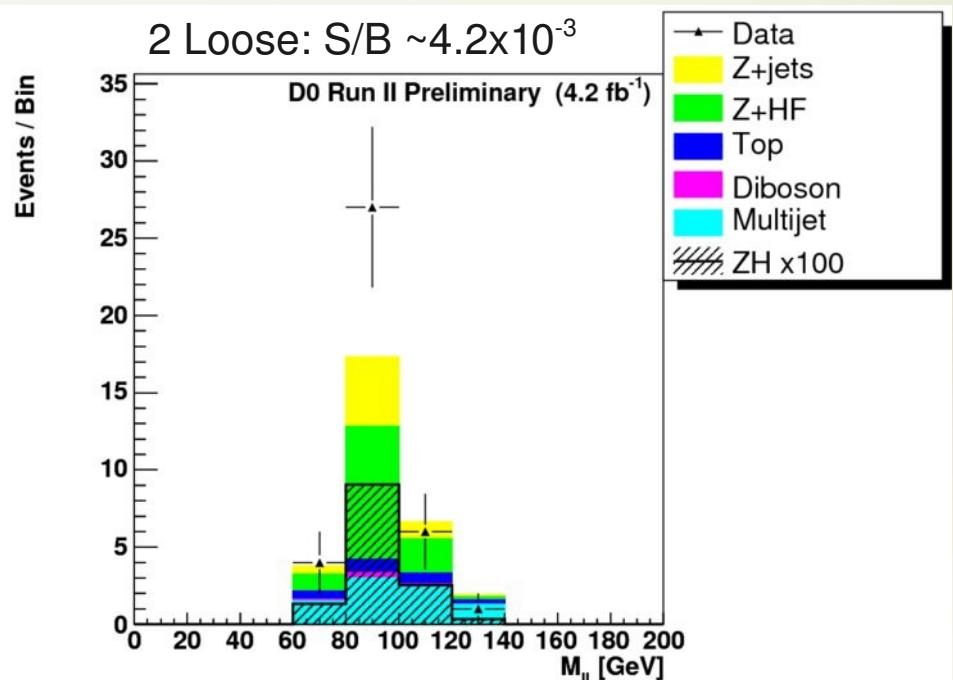
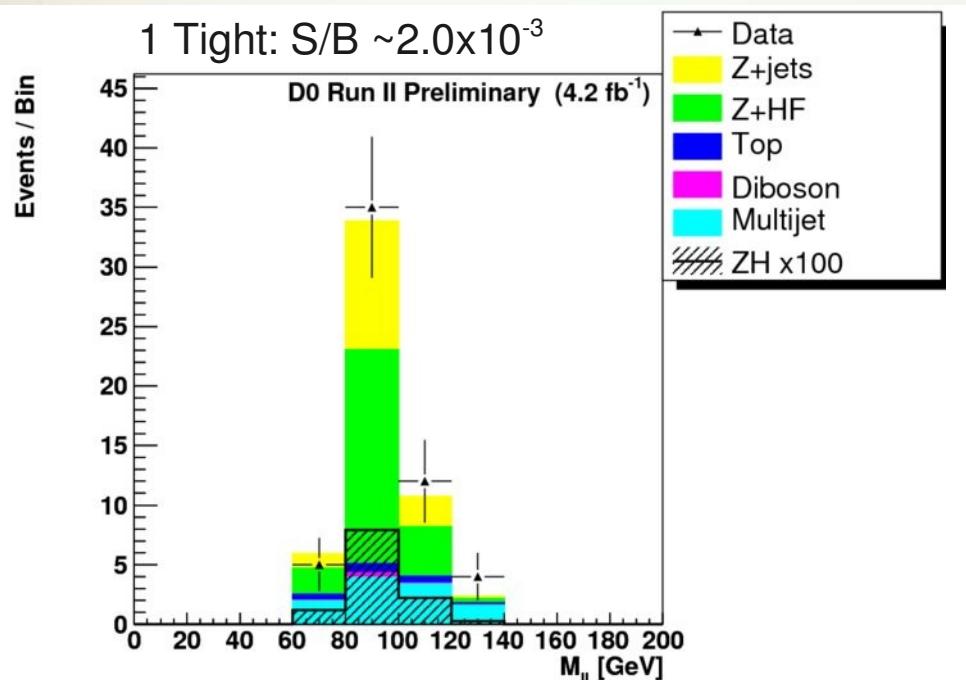
- 1) =1 Very Tight b-tagged jet, ≥ 1 untagged jet
- 2) ≥ 2 Loose b-tagged jets

Vertex Tagging (transverse)

(Signed) Track Impact Parameter (dca)

Hard Scatter

Decay Length (L_{xy})

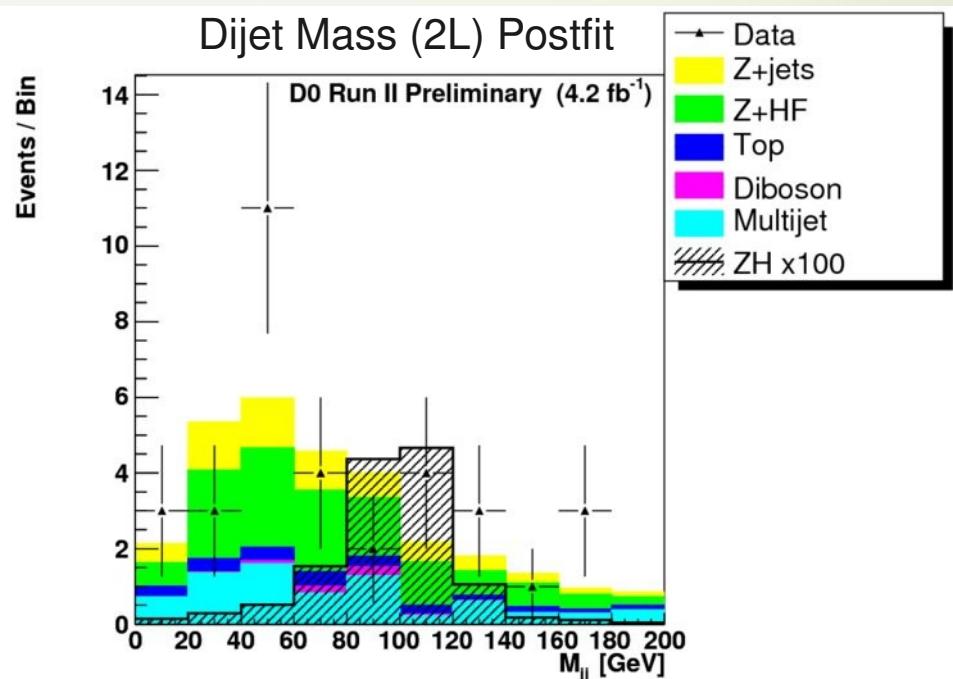
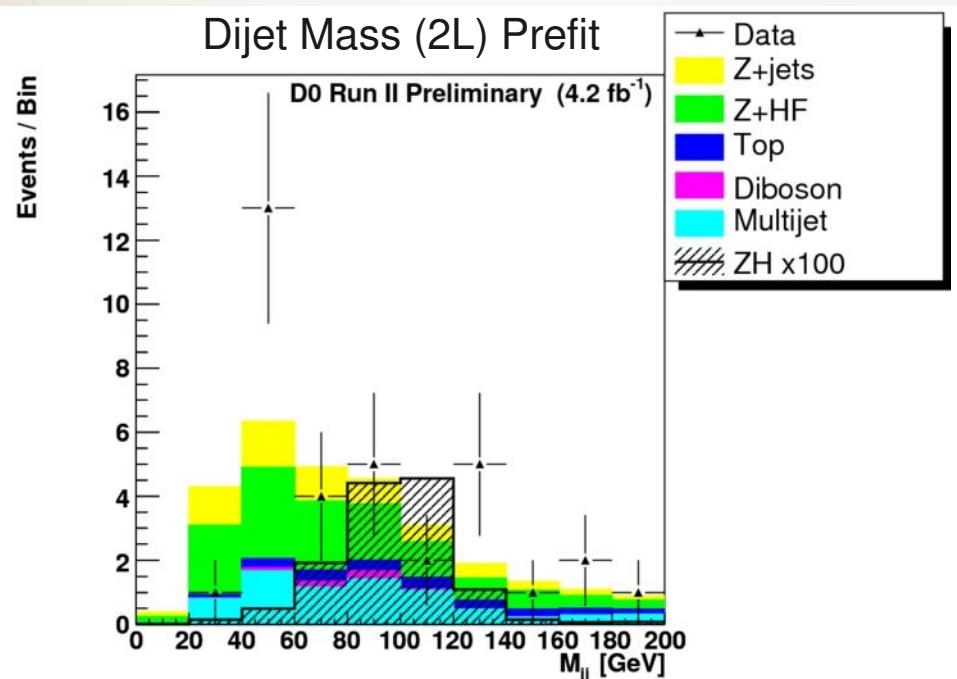


Kinematic Fit : Dijet Mass

In a perfect detector, there would be very little MET in $ZH \rightarrow llbb$ events.
Given our knowledge of the jet and lepton energy resolutions, we can improve our measurements after the fact for a 6-11% improvement in sensitivity in all channels.

Perform a multi-dimensional fit on the p_T , η , and ϕ of the two leptons and two jets with:

- 1) $M_{ll} = 91.2 \pm 2.5 \text{ GeV}$
- 2) $\sum p_T = 0.0 \pm 7.0 \text{ GeV}$



Kinematic Fit : Chisq

Cut at 20 on the Kinematic Fit's χ^2

Yield Reductions:

Data: 30%

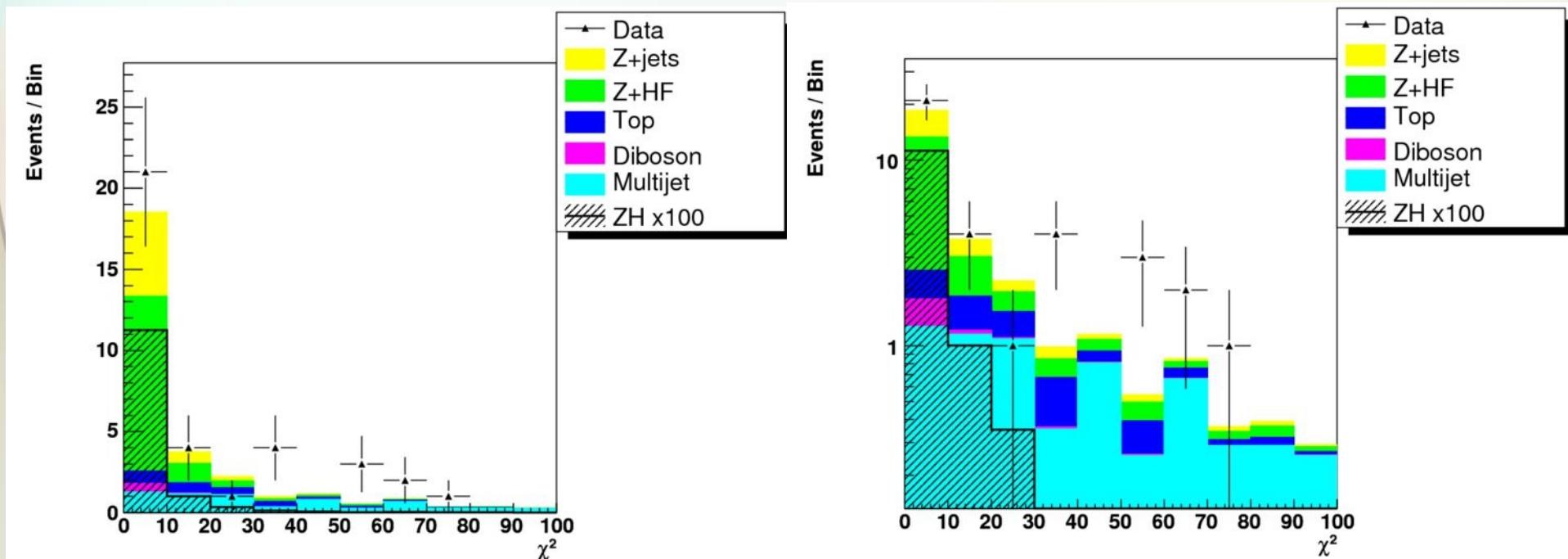
Signal: 5%

Multijet: 69%

All Bkgd: 18%

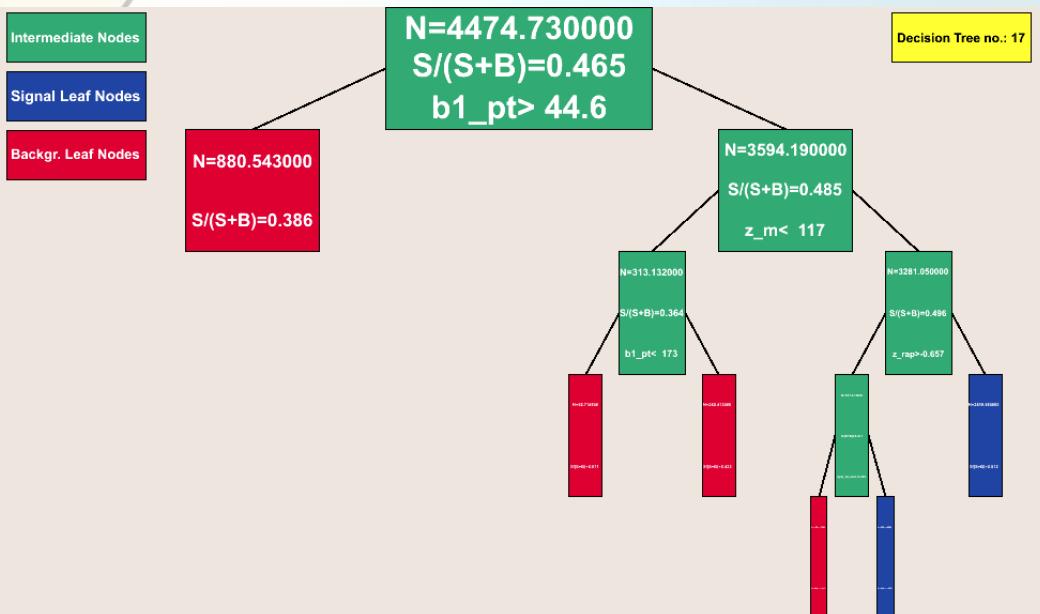
Improve expected $\mu + \text{trk}$ limit by 14%

Improvement in the three other channels, where there is less multijet background, is more modest (1-5%)

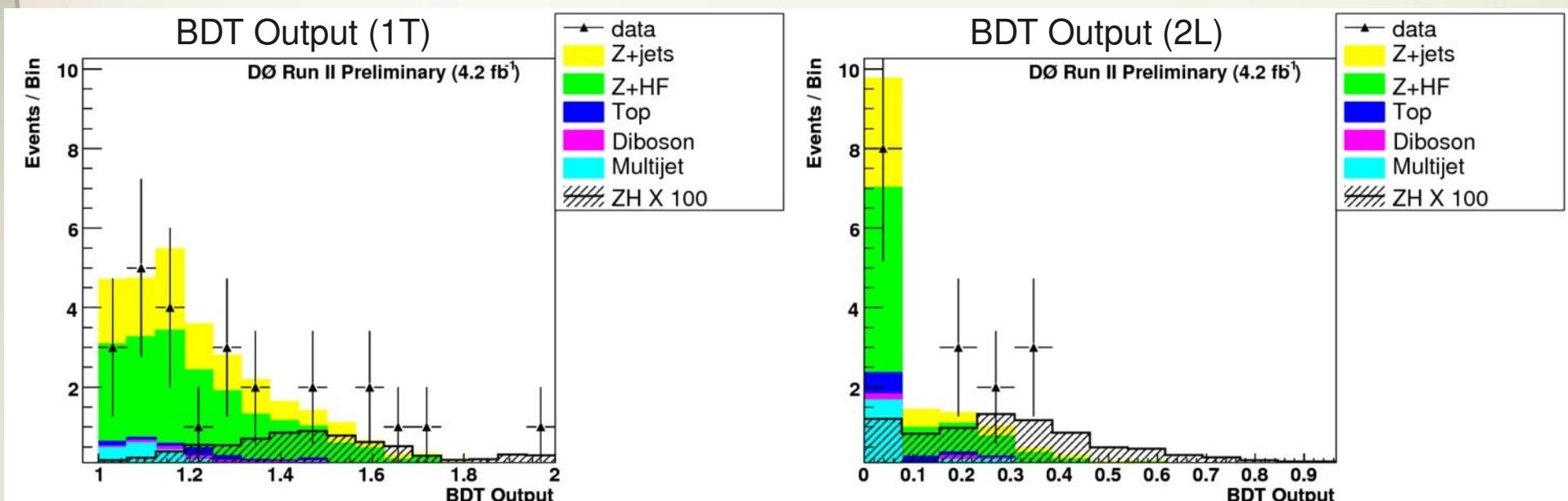


Multivariate Classifier

Use a **Boosted Decision Tree** as final discriminant:



~35% more sensitivity than using a 1D cut on Dijet Mass



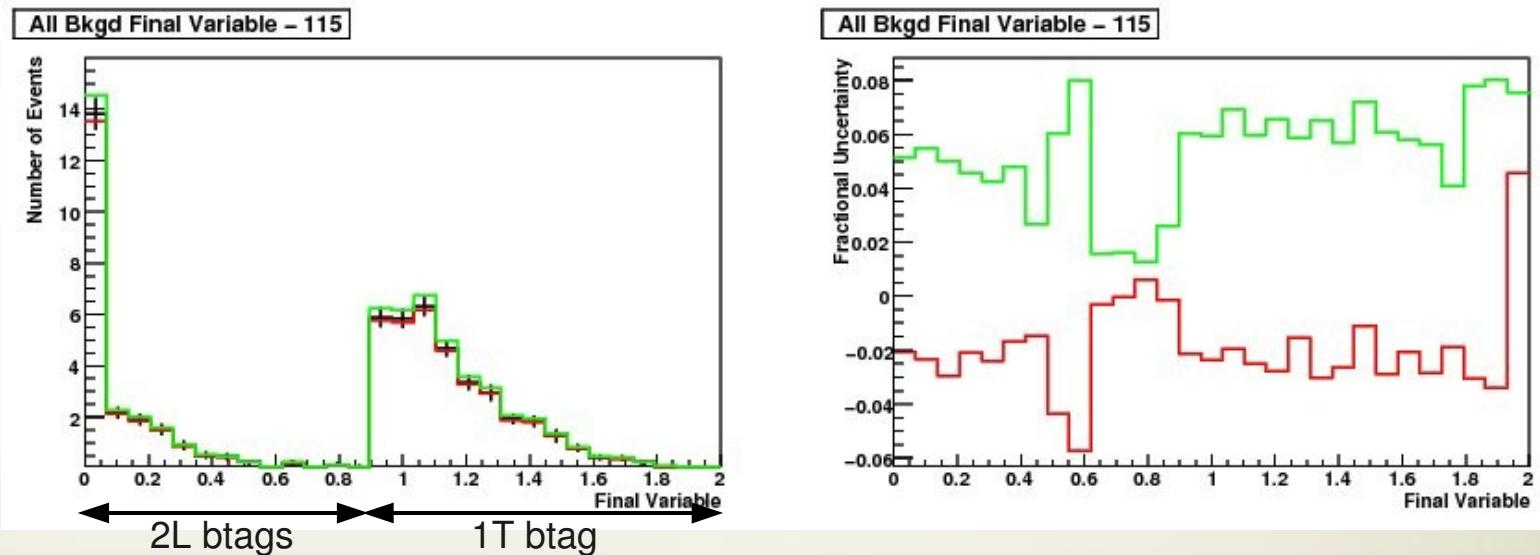
Systematic Uncertainties

As with $ZZ \rightarrow llvv$: Consider two types of systematics:

Normalization – Uncertainties which affect the overall normalization

Shape – Uncertainties which have an intrinsic shape (eg. vary with pT), or pick up a shape when convoluted by the multivariate classifier (eg. due to variable correlations).

Considered > 25
systematic sources



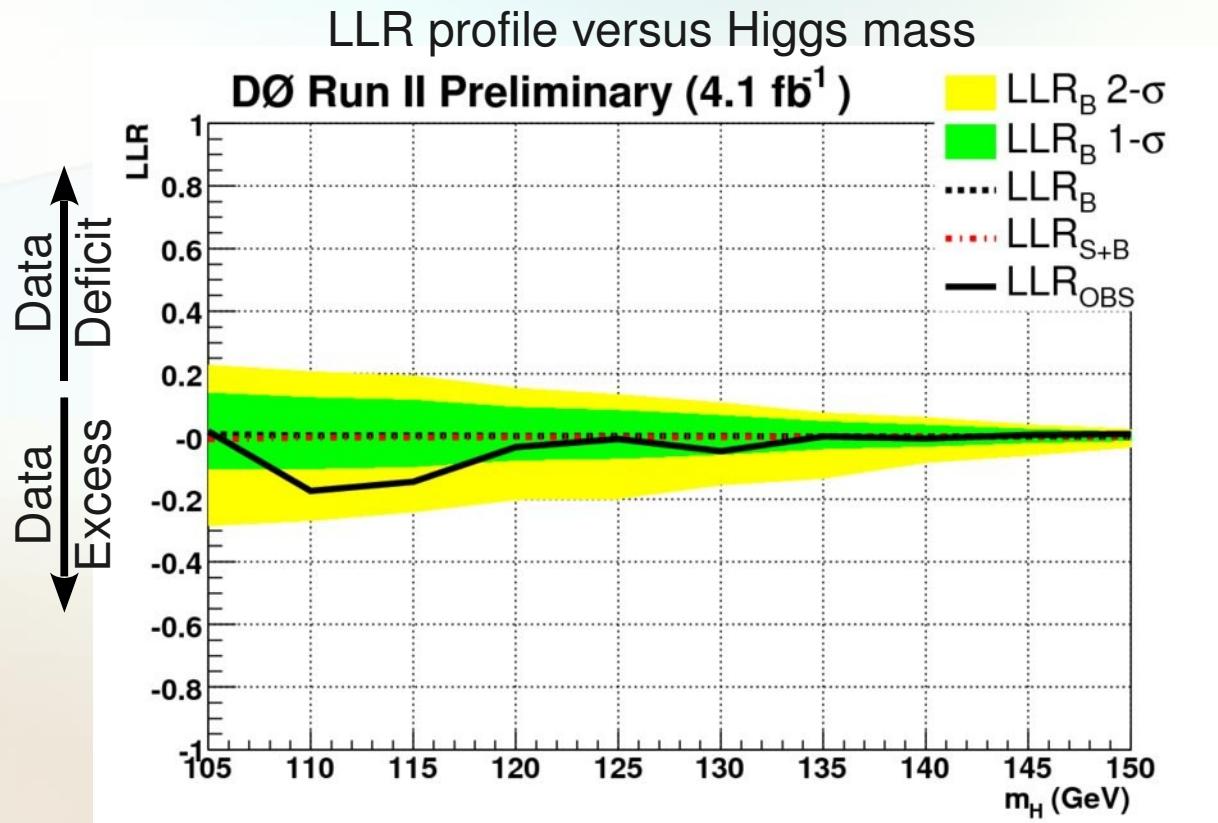
Change due to varying the Jet Energy Scale
absolute on the left, fractional on the right.

Heavy hitting systematics:

- Z+HF cross section: 30%
- Multijet normalization: 25%
- HF Scale: 12%
- Jet Energy Scale: 10-20%

Log Likelihood Ratio : Take 2

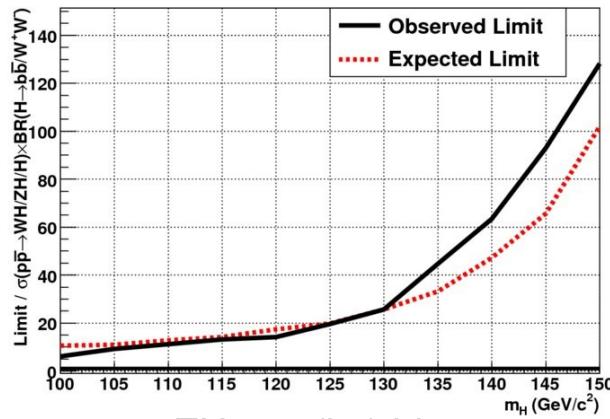
As with the ZZ analysis: Use likelihood ratios as a test statistic
Calculate LLR for each Higgs mass and plot the profile



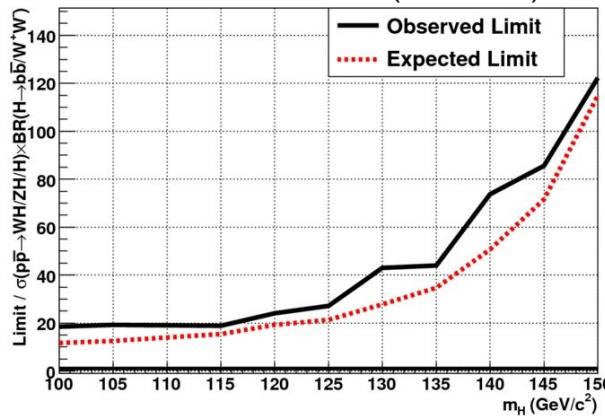
This semi-frequentist approach allows us to combine the results from many search channels, as well as incorporate the effect of the systematic uncertainties (random Gaussian sampling).

ZH \rightarrow llbb Limits

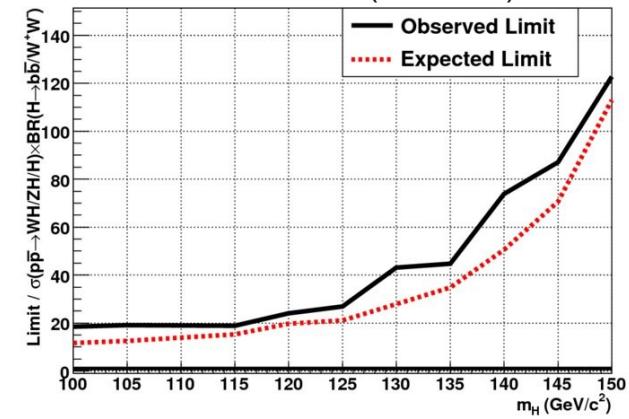
ZH \rightarrow mu mu bb



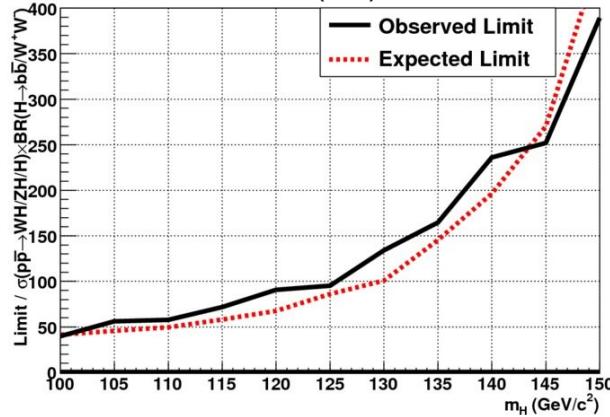
ZH \rightarrow ee bb (CC-CC)



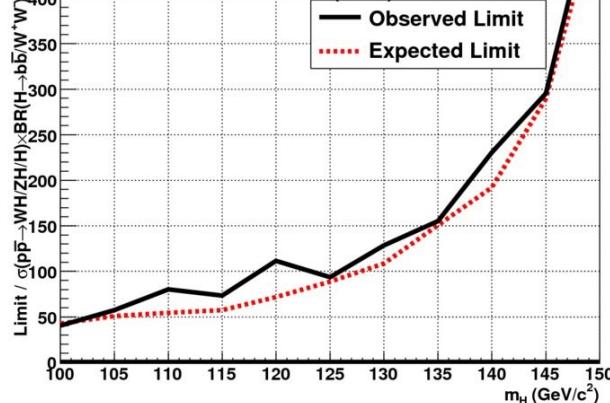
ZH \rightarrow ee bb (CC-EC)



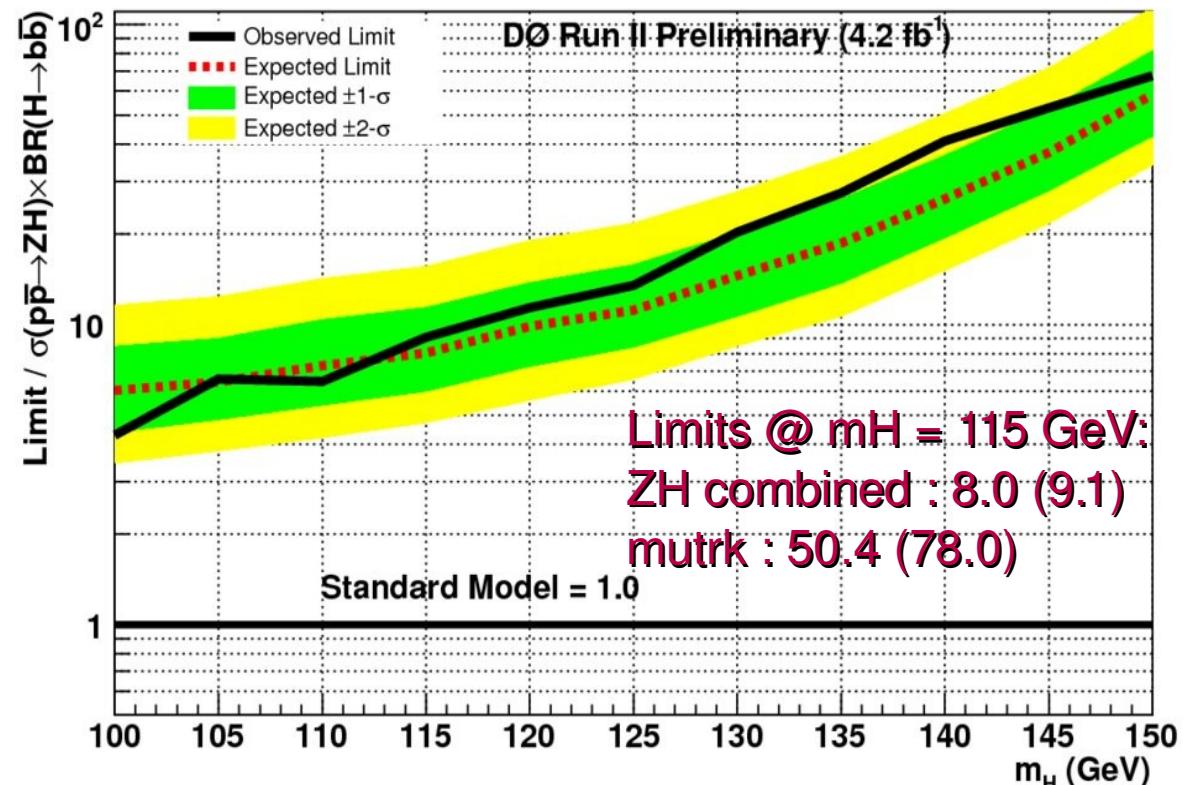
ZH \rightarrow e(icr) bb



ZH \rightarrow mu(trk) bb

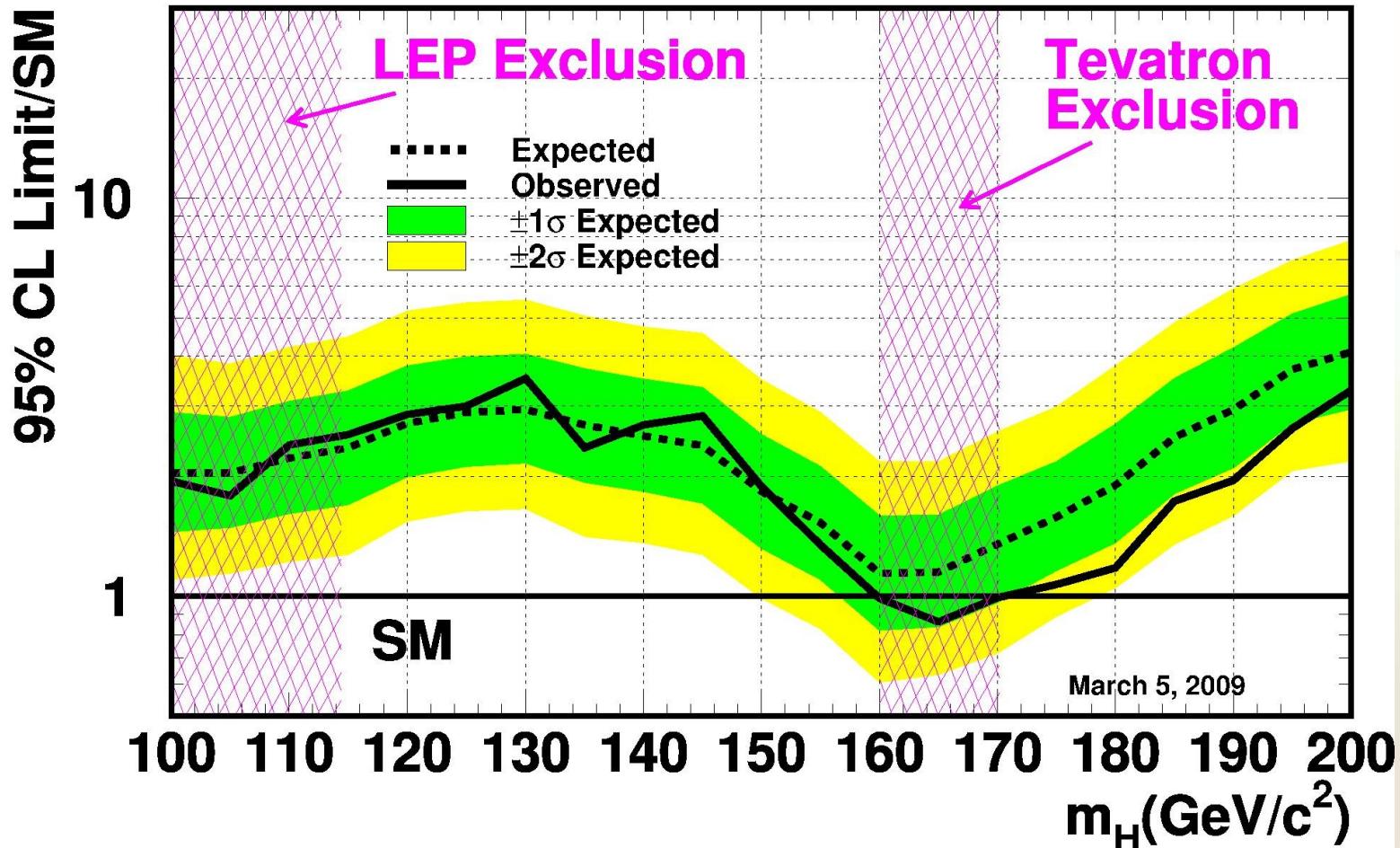


ZH \rightarrow ll bb Combined



Higgs Exclusion at the Tevatron

Tevatron Run II Preliminary, $L=0.9\text{-}4.2 \text{ fb}^{-1}$



Conclusion

Strong physics program at the Tevatron with Higgs analyses using $> 6.5(?) \text{ fb}^{-1}$ likely to be included in the Tevatron combination for the Summer 2k9 results.

Continue to improve our arsenal with 1st observations of processes like ZZ production.

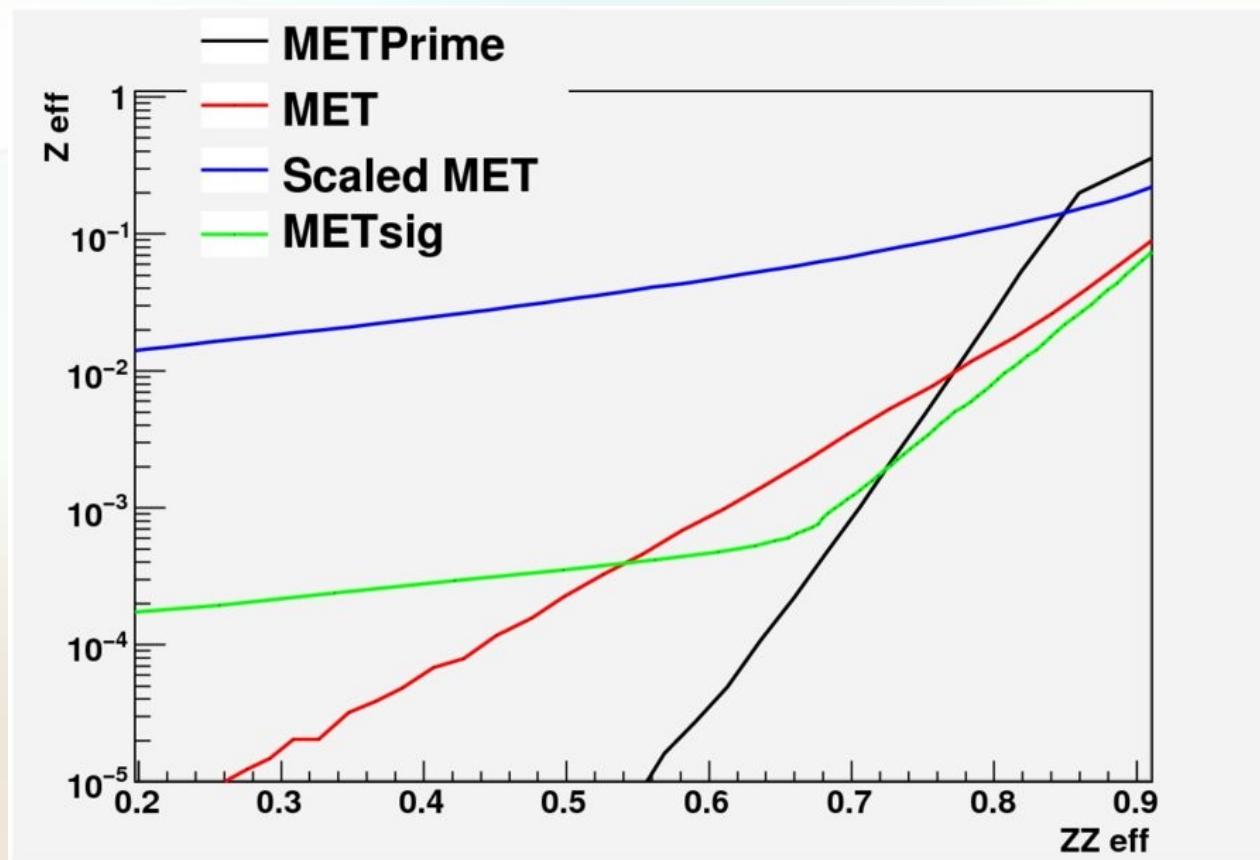
Sharing analysis techniques will lead to further improvements in new physics searches.

With nothing but the currently developed analysis improvements, expect to be able to exclude $m_H < 120$ and $140 < m_H < 190 \text{ GeV}$ with the full Tevatron dataset.

Backup Slides

Why METPrime?

Compute acceptance for Z and ZZ for several MET types.



b-tagging

NN Input Variables (by rank):

- Decay Length Significance of the Secondary Vertex
- Weighted combination of the tracks' IP significancies
- Probability that the jet originates from the PV
- Chi Square per degree of freedom of the SV
- Number of tracks used to reconstruct the SV
- Mass of the SV
- Number of SV found in the jet

NN Tag points used in this analysis: L4 ($NN > 0.2$) and VERYTIGHT ($NN > 0.85$)

Tag Efficiency measured using System8 formalism (8 eqns, 8 unkowns, 2 tag methods)

Data/MC Scale Factor from the ratio of the muonic data/MC efficiencies

BDT Variables

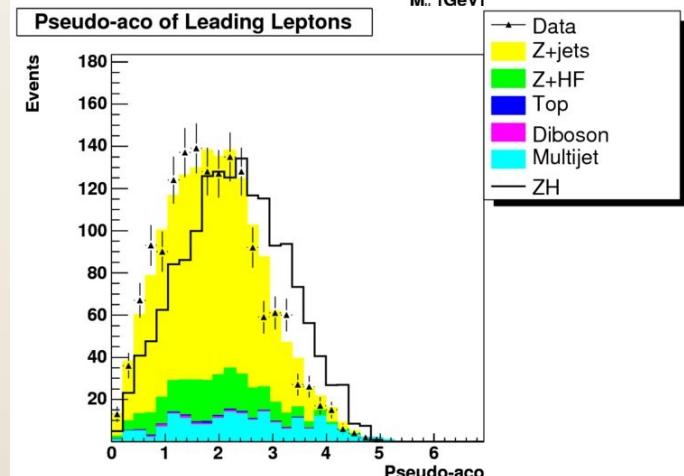
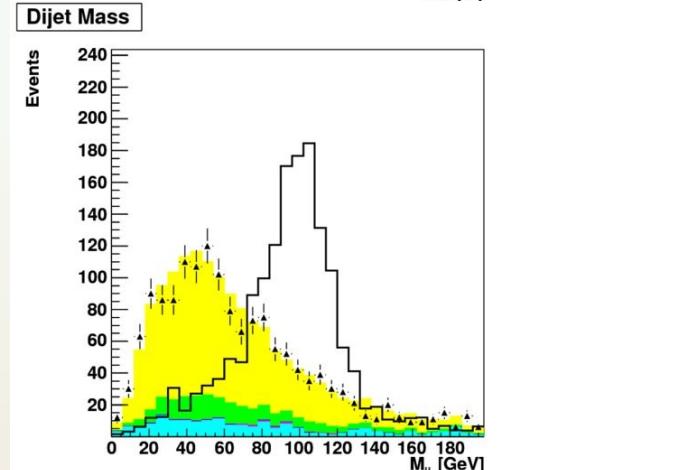
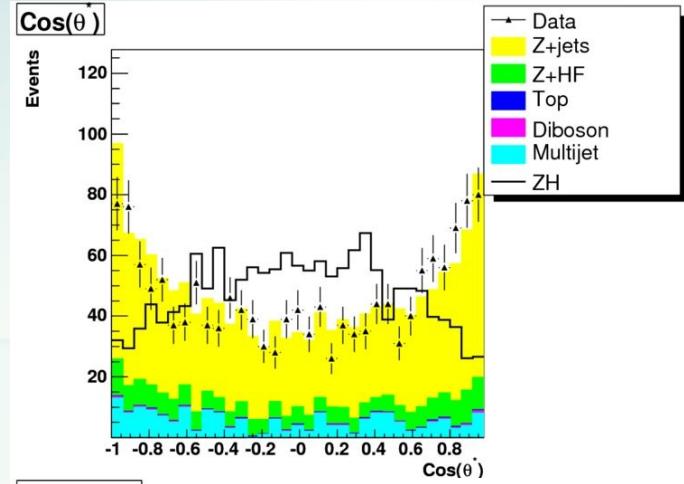
: Ranking result (top variable is best ranked)

: -----
: Rank : Variable : Variable Importance
: -----

```

: 1 : z_dr           : 1.983e-01
: 2 : mbb_massless_fit : 1.454e-01
: 3 : b1_pt          : 6.853e-02
: 4 : z_m            : 6.565e-02
: 5 : mbb_massless   : 6.306e-02
: 6 : met             : 5.825e-02
: 7 : z_pseudo_aco   : 4.707e-02
: 8 : cos_theta_star  : 4.006e-02
: 9 : cos_chi_star    : 3.655e-02
: 10 : dijet_deta     : 3.525e-02
: 11 : dphi_zdijet    : 2.900e-02
: 12 : b2_pt           : 2.646e-02
: 13 : dijet_pt         : 2.626e-02
: 14 : dijet_dphi       : 2.612e-02
: 15 : mbb             : 2.171e-02
: 16 : dijet_mt         : 1.712e-02
: 17 : b1_eta           : 1.576e-02
: 18 : z_rap             : 1.480e-02
: 19 : theta_l1l2        : 1.479e-02
: 20 : dijet_fit_eta      : 1.399e-02
: 21 : z_eta              : 1.059e-02
: 22 : theta_b1b2        : 1.007e-02
: 23 : dphi_dijetmet      : 8.280e-03
: 24 : z_colinearity       : 6.974e-03
: 25 : boost_perp_fit      : 5.384.e-03
: -----
```

University



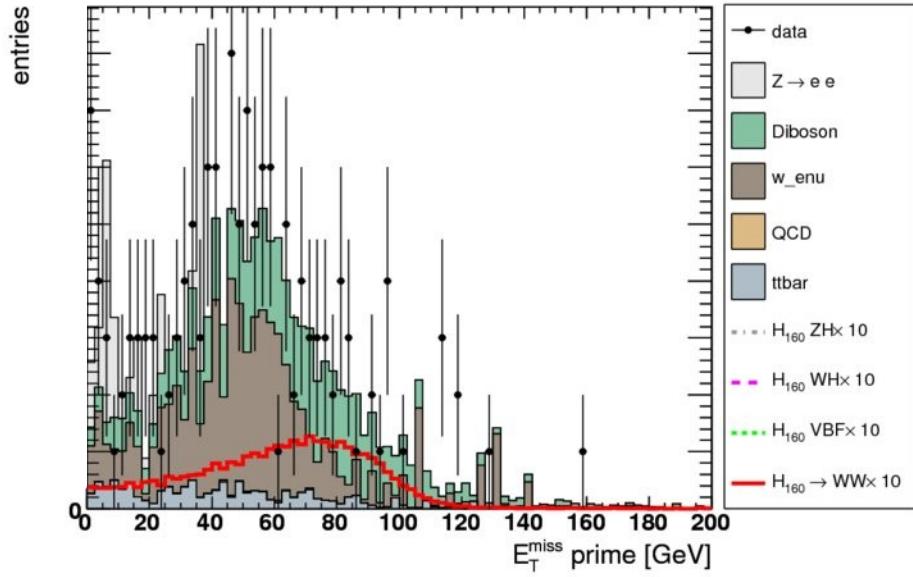
ZH Limits

	p20 $\mu\mu$		p20 diem		p17+p20 mu+track		p20 e+icr		combination	
m_H (GeV)	Exp/SM	Obs/SM	Exp/SM	Obs/SM	Exp/SM	Obs/SM	Exp/SM	Obs/SM	Exp/SM	Obs/SM
100	9.29	7.7	11.4	18.5	38.6	43.4	42.3	38.0	7.25	6.11
105	11.1	9.0	12.6	19.2	43.2	45.3	45.6	53.8	7.78	9.09
110	12.8	10.9	14.6	17.0	46.7	69.7	50.2	56.3	9.08	9.54
115	14.7	13.3	15.3	18.7	50.4	78.0	57.0	68.2	9.98	11.1
120	17.7	14.2	19.2	23.9	63.4	75.2	68.8	87.7	12.2	12.6
125	20.7	19.5	20.9	27.0	74.1	86.7	85.5	91.2	13.7	15.4
130	26.2	25.6	27.4	42.4	90.4	120	102	130	17.5	24.6
135	34.2	44.1	34.9	43.6	126	142	146	159	22.6	31.6
140	47.9	62.0	50.3	73.2	167	188	198	232	31.7	49.3
145	64.9	91.5	69.2	85.5	250	252	269	243	44.3	56.0
150	104	129.3	114	123	428	331	457	380	71.7	75.5

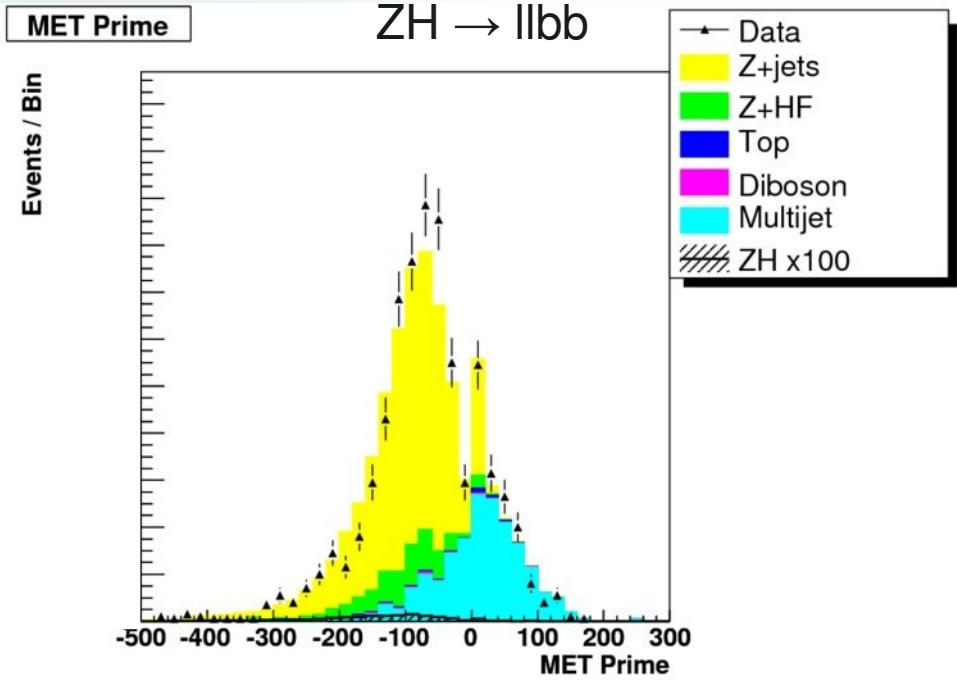
The Story's Not Over Yet

METPrime is getting an extended lease on life in Higgs searches:

$H \rightarrow WW \rightarrow e\nu e\nu$



$ZH \rightarrow llbb$



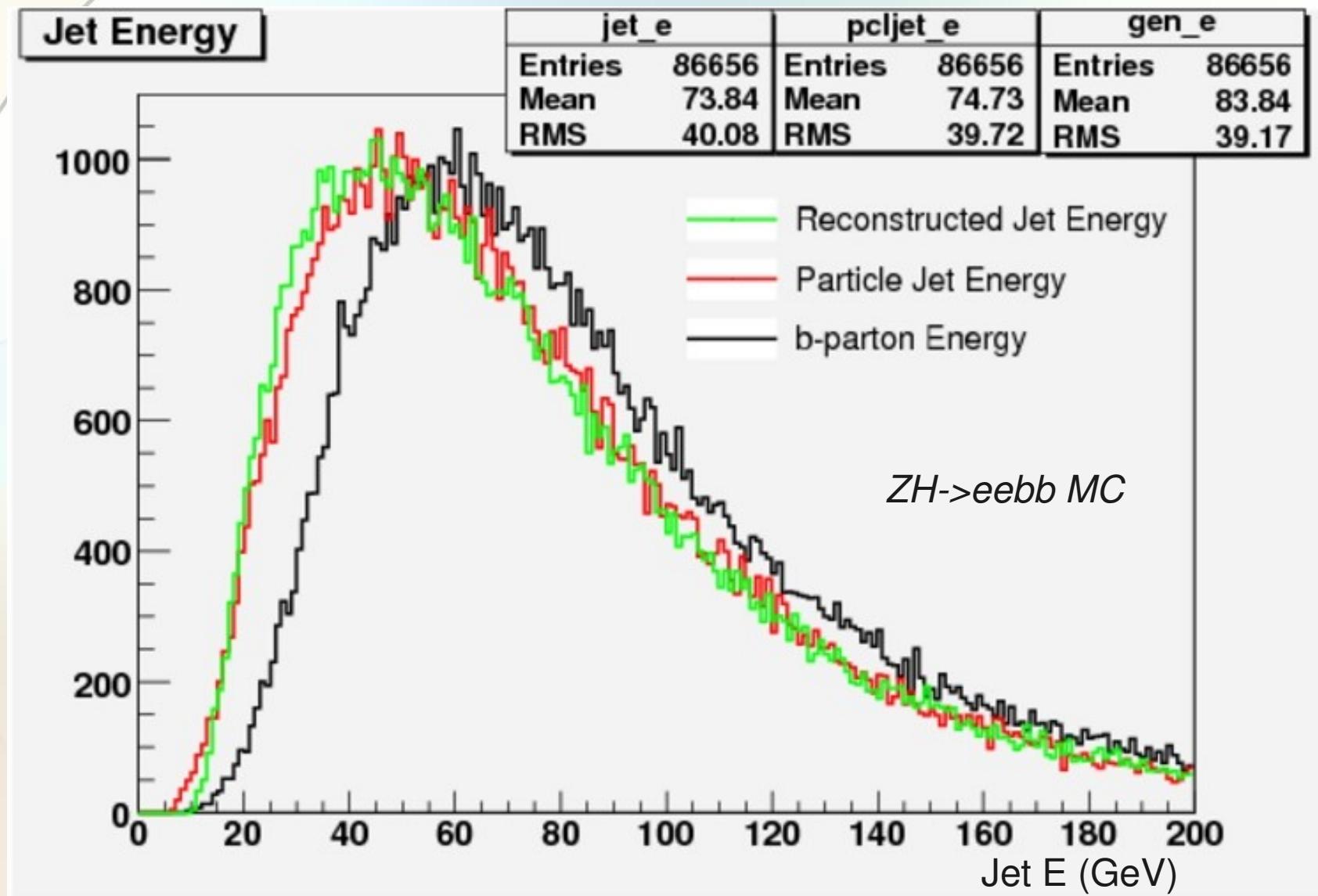
In $H \rightarrow WW \rightarrow llvv$:

- 4 Cuts on MET and related variables could be replaced by one on MET'
- Shape difference between signal and background could be used by their NN
- Select events with genuine MET

In $ZH \rightarrow llbb$:

- Feed the shape into the Boosted Decision Tree to select events with no MET

JER: The Motivation



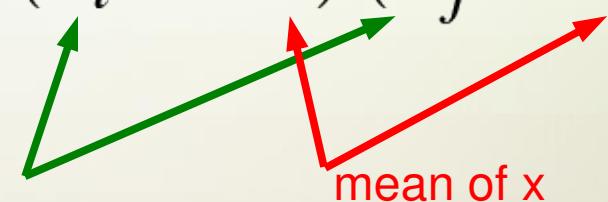
JES gets you to the particle jet level
Want to get from a particle jet measurement to a b-parton measurement

JER: The Technique

- Collect a set of variables (~ 70) and compute their correlation factors to find those with predictive power
- Construct an H-Matrix, trained on a set of ($N-1$) observables and the parton energy

$$H = M^{-1} \rightarrow M_{ij} = \frac{1}{K} \sum_{k=1}^K (x_i^k - \bar{x}_i)(x_j^k - \bar{x}_j)$$

observed variable



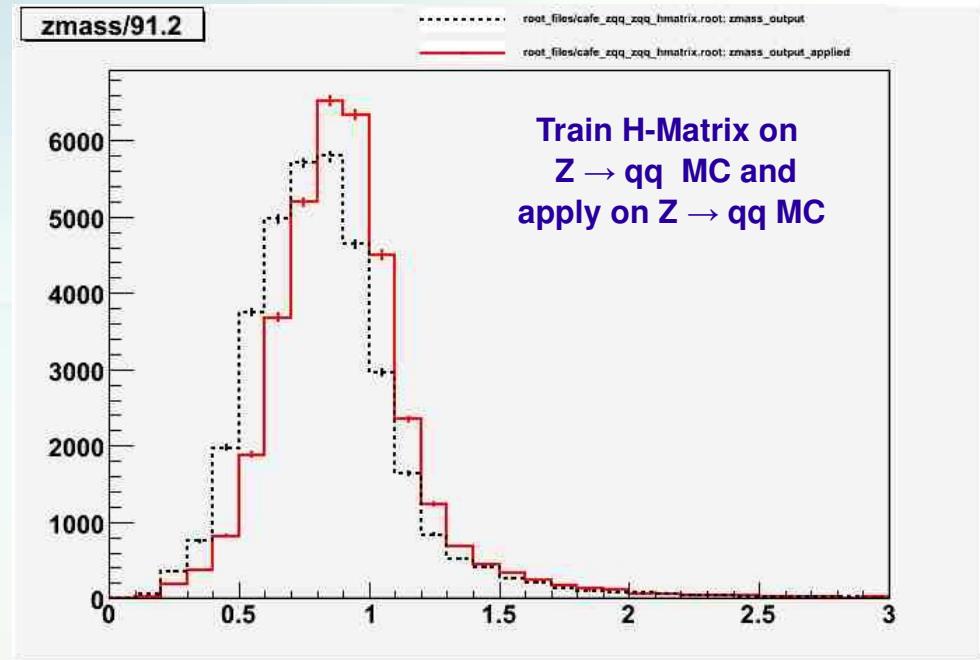
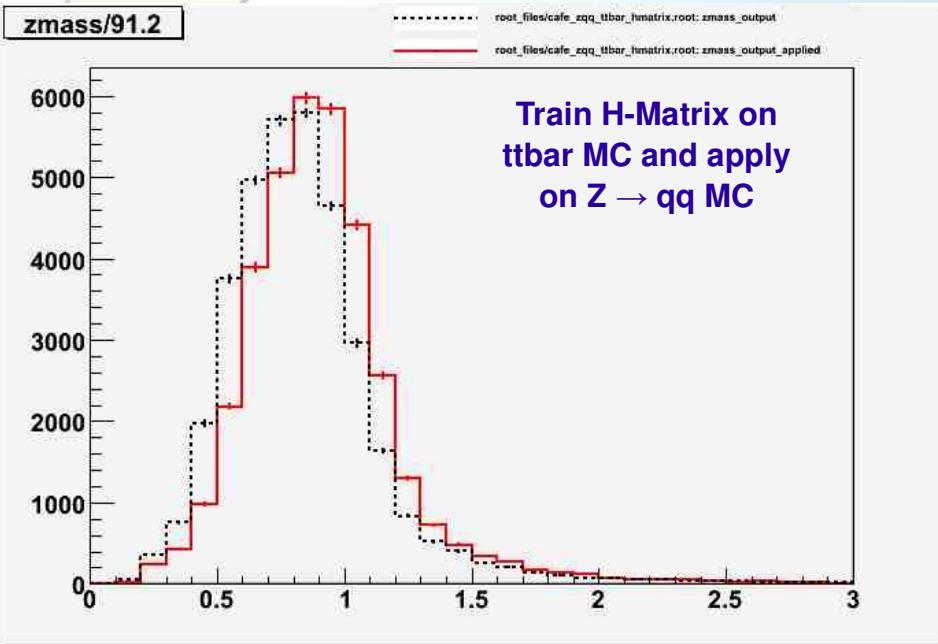
After computing the H matrix, predict the parton energy using:

$$x_N = \bar{x}_N - \sum_{j=1}^{N-1} H_{jN} (x_j - \bar{x}_j) / H_{NN}$$

mean parton E

Major advantage to the method is its simplicity!
Emanuel Strauss – Stony Brook University

JER: The Example



Fit the Z peak to a Gaussian within Mean ± 1 RMS

Before correction:

Mean: 0.779729

Width: 0.235227

After ttbar correction:

Mean: 0.867207

Width: 0.220042

After zqq correction:

Mean: 0.872341

Width: 0.196718

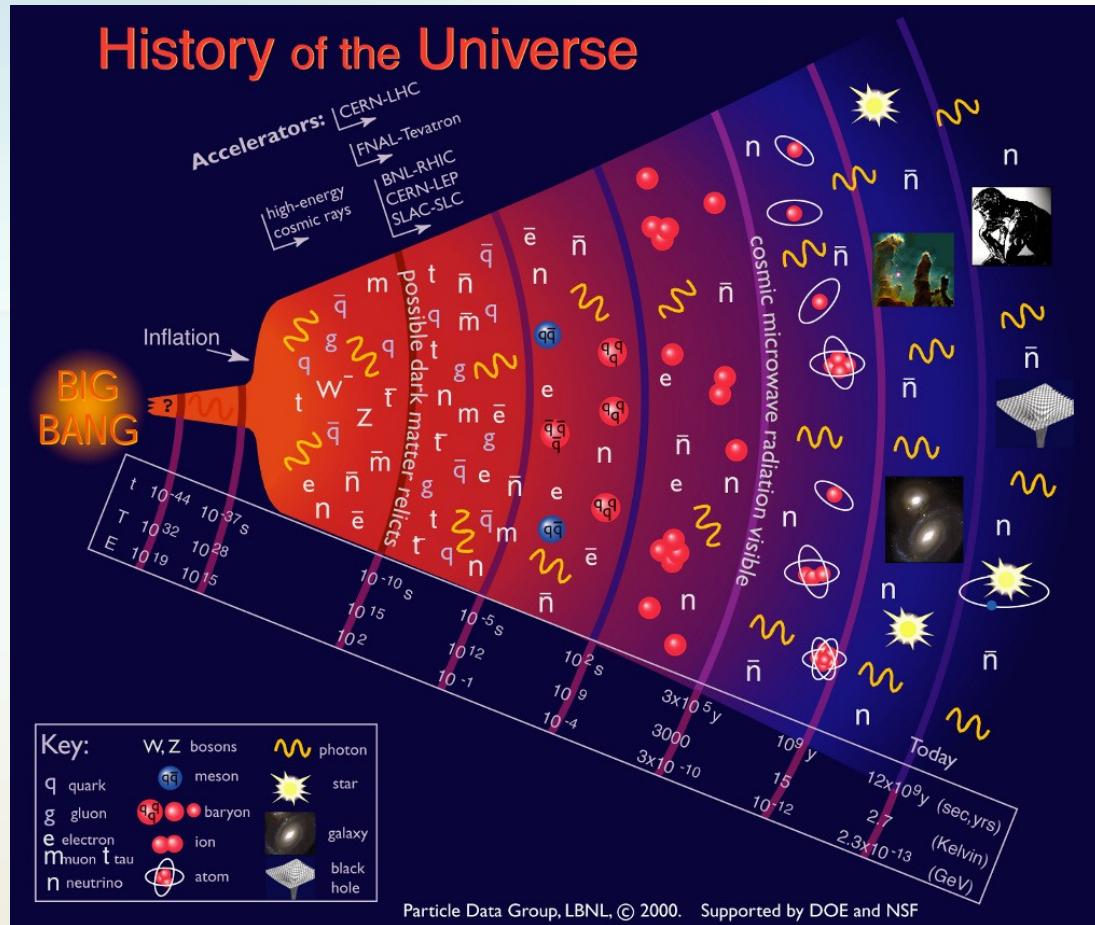
Light jet correction is relatively sample independent

What are We Doing ?

What does a time machine really look like?



Particle colliders create conditions similar to the early universe, fractions ($\sim 10^{-12}$) of a second after the Big Bang.



Accelerating subatomic particles (protons and anti-protons) to nearly the speed of light before smashing them together produces exotic material.

Study the resulting particles to better understand the fundamental forces of the universe and the laws which dictate how we got where we are now.

The Standard Model

The standard model represents our best understanding of the physical world to date.

Describes the constituents of matter: **Quarks and Leptons**

As well as the forces that govern them through the exchange of force carriers:

Type	Strength	Range	Mediator
Strong	1	10^{-15} m	8 gluons
Electro-Magnetic	10^{-2}	inf	photon
Weak	10^{-5}	10^{-18} m	W^+, W^-, Z^0
Gravity*	10^{-38}	inf	gravity

* Gravity is not described by the standard model

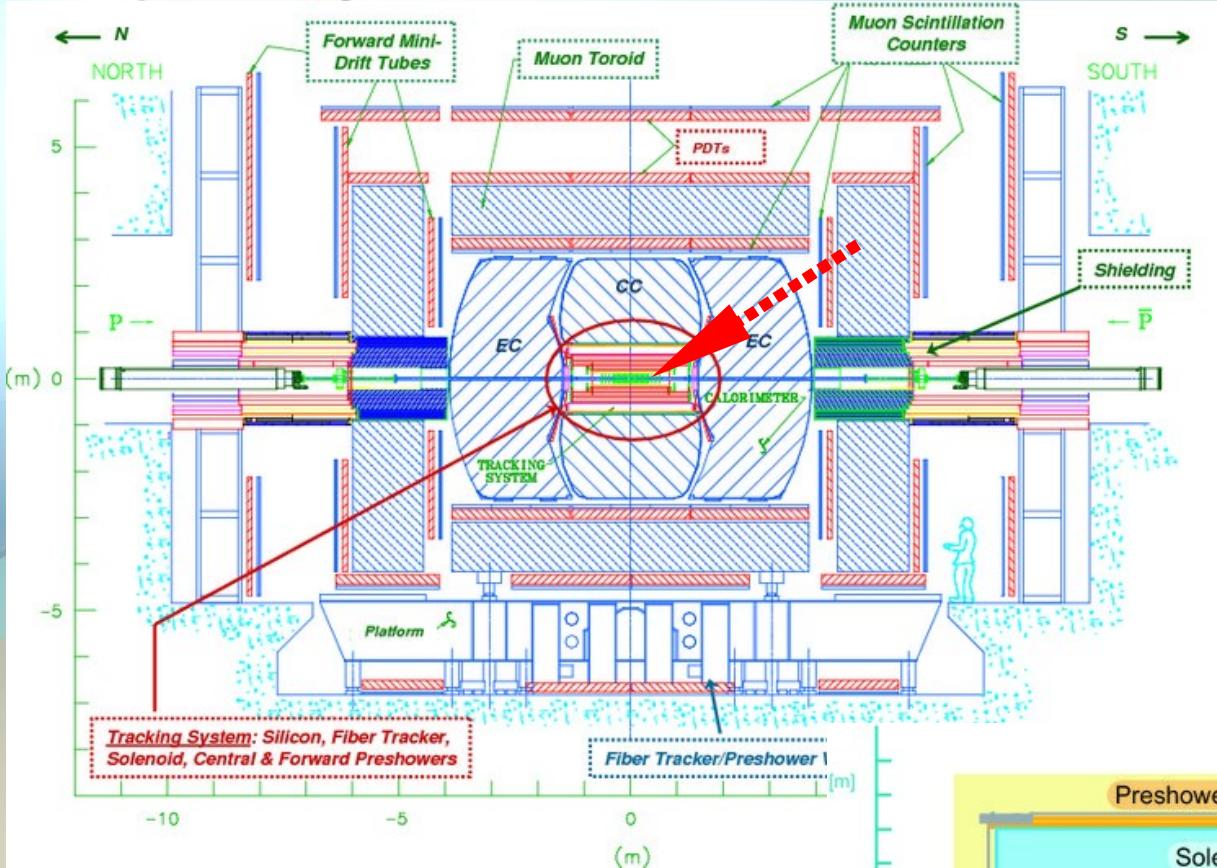
Quantum field theory provides the mathematical framework for the standard model.

Each particle is described in terms of a dynamical field which permeates space-time.

Three Generations of Matter (Fermions)				
Quarks	I	II	III	
	mass → charge → spin → name →	2.4 MeV $\frac{2}{3}$ $\frac{1}{2}$ u up	1.27 GeV $\frac{2}{3}$ $\frac{1}{2}$ c charm	171.2 GeV $\frac{2}{3}$ $\frac{1}{2}$ t top
	4.8 MeV $-\frac{1}{3}$ $\frac{1}{2}$ d down	104 MeV $-\frac{1}{3}$ $\frac{1}{2}$ s strange	4.2 GeV $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 g gluon
	<2.2 eV 0 $\frac{1}{2}$ v _e electron neutrino	<0.17 MeV 0 $\frac{1}{2}$ v _μ muon neutrino	<15.5 MeV 0 $\frac{1}{2}$ v _τ tau neutrino	91.2 GeV 0 1 Z ⁰ weak force
Leptons	0.511 MeV -1 $\frac{1}{2}$ e electron	105.7 MeV -1 $\frac{1}{2}$ μ muon	1.777 GeV -1 $\frac{1}{2}$ τ tau	80.4 GeV ± 1 $\frac{1}{2}$ W [±] weak force

Bosons (Forces)

The D0 Detector: Tracking



1) Silicon Microstrip Tracker

$$|\eta| < 3$$

Barrel and disk silicon semiconductors

2) Central Fiber Tracker

$$|\eta| < 1.7$$

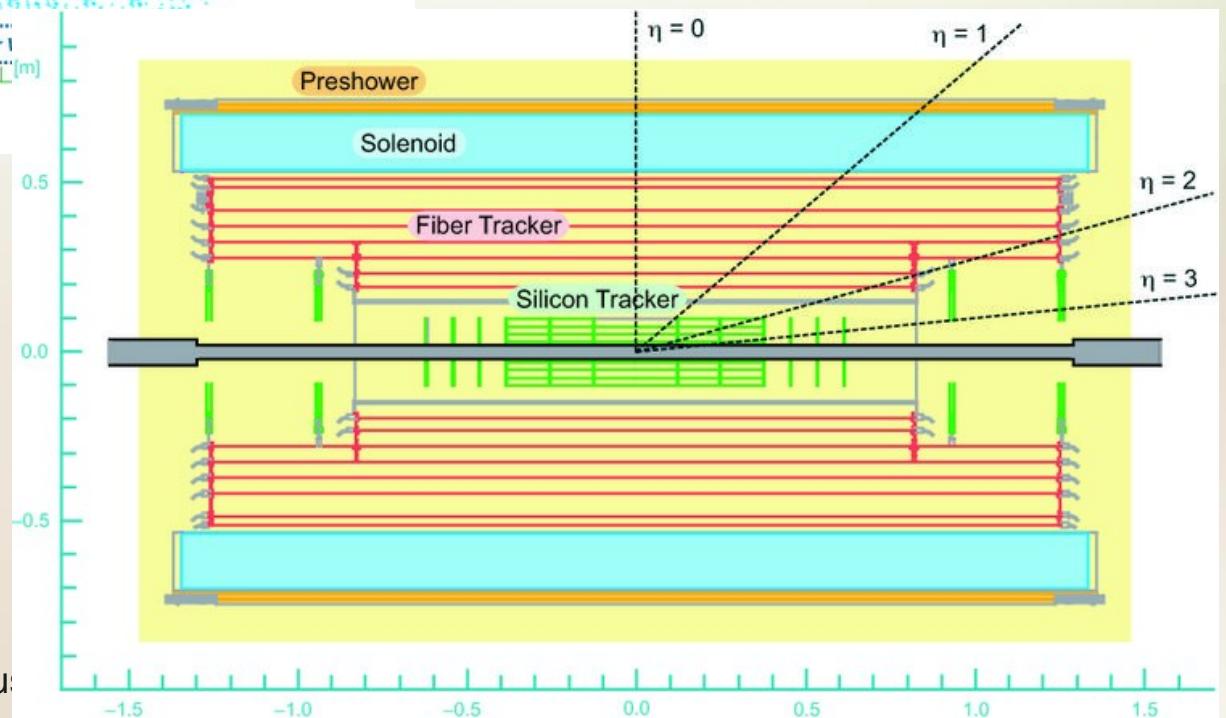
8 layers of scintillating fiber

Central Tracking:

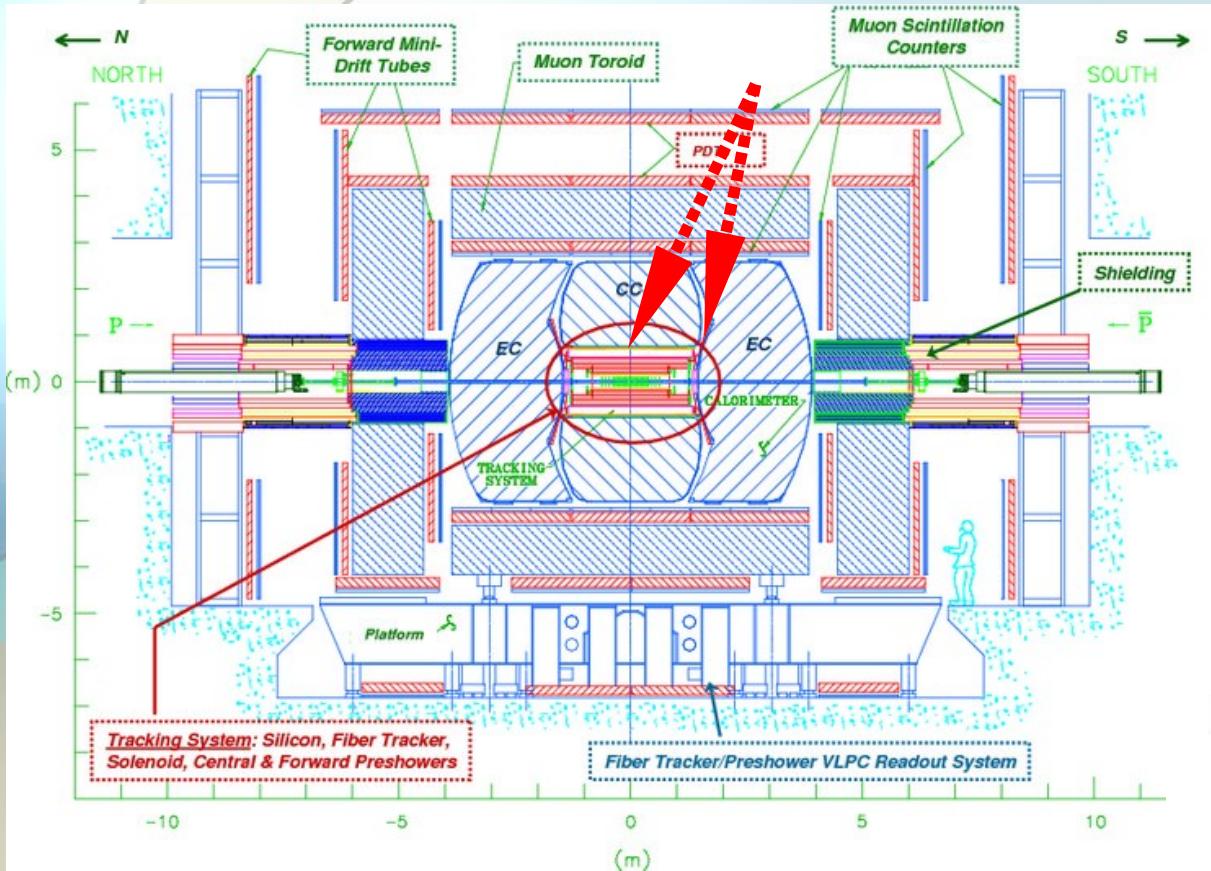
Two inner most detectors, enclosed in a **Solenoid magnet** (2.0 Tesla)

Precise position and momentum measurements of charged particles.

Vertex Determination



The D0 Detector: Preshower



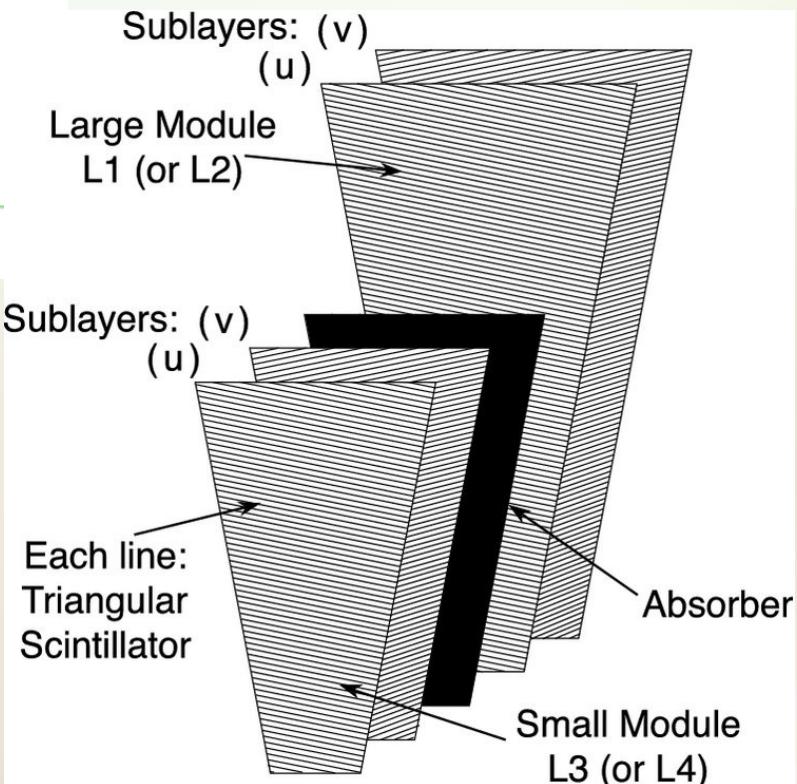
- 1) Central
 $|\eta| < 1.3$
 3 cylindrical layers of scintillating strips
 fixed on a lead radiator
- 2) Forward
 $1.5 < |\eta| < 2.5$
 2 layers of scintillating strips sandwiching a
 lead-stainless-steel absorber

Pre-Shower:

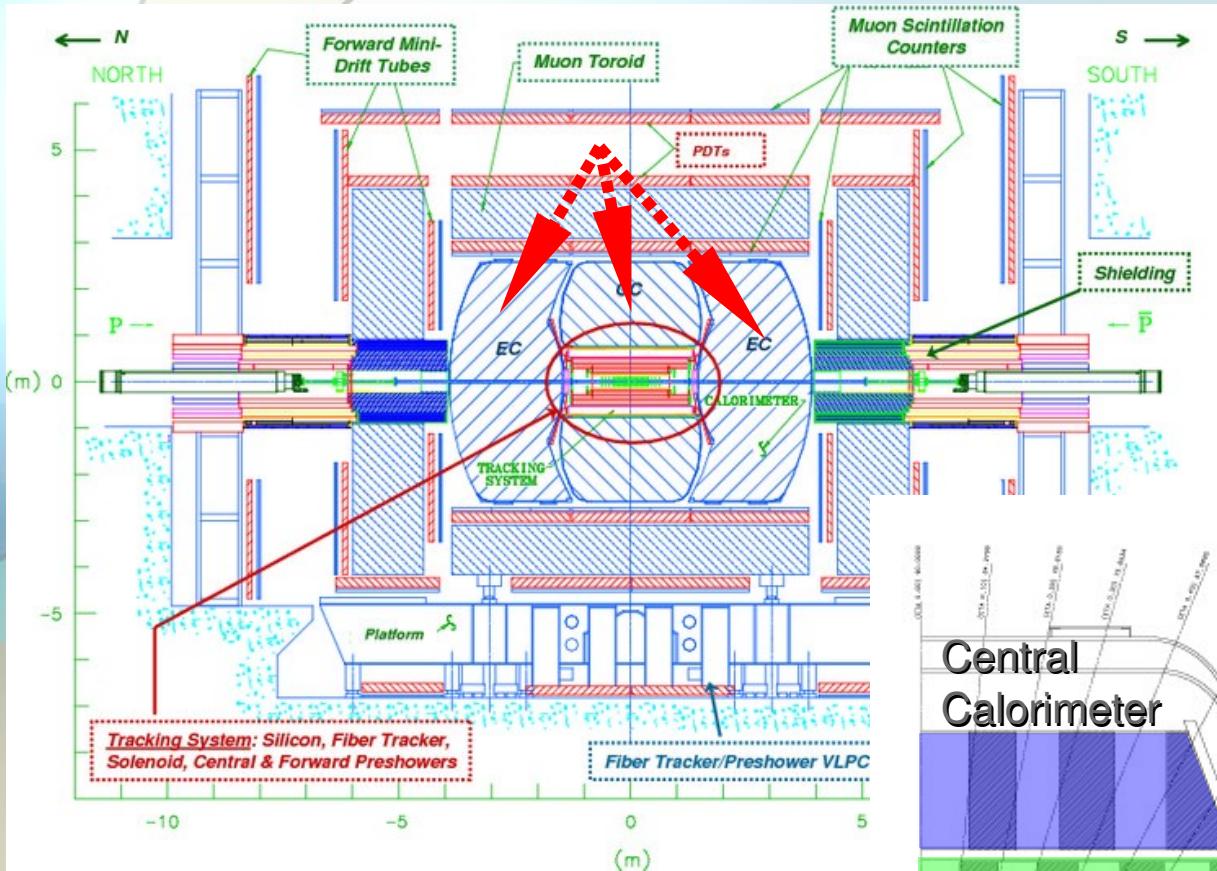
A tracker/calorimeter hybrid made of Scintillating Fibers and Absorbing Plates

Fibers are similar to those in the CFT

Improves energy measurement for showers beginning outside of the calorimeter.



The D0 Detector: Calorimeter



Full coverage: $|\eta| < 4.2$

- 4 Electromagnetic Layers
- 3 Fine Hadronic Layers
- 1 Coarse Hadronic Layer

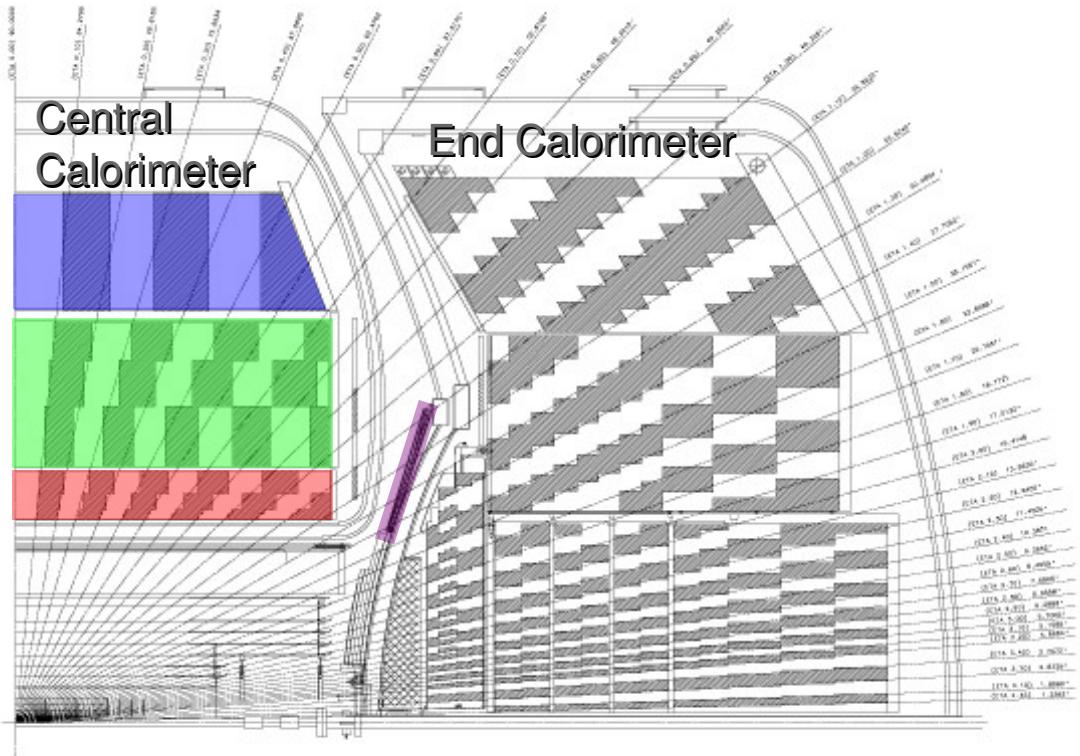
Gap @ $1.1 < |\eta| < 1.5$ covered by the
Inner Cryostat Detector

Calorimetry:

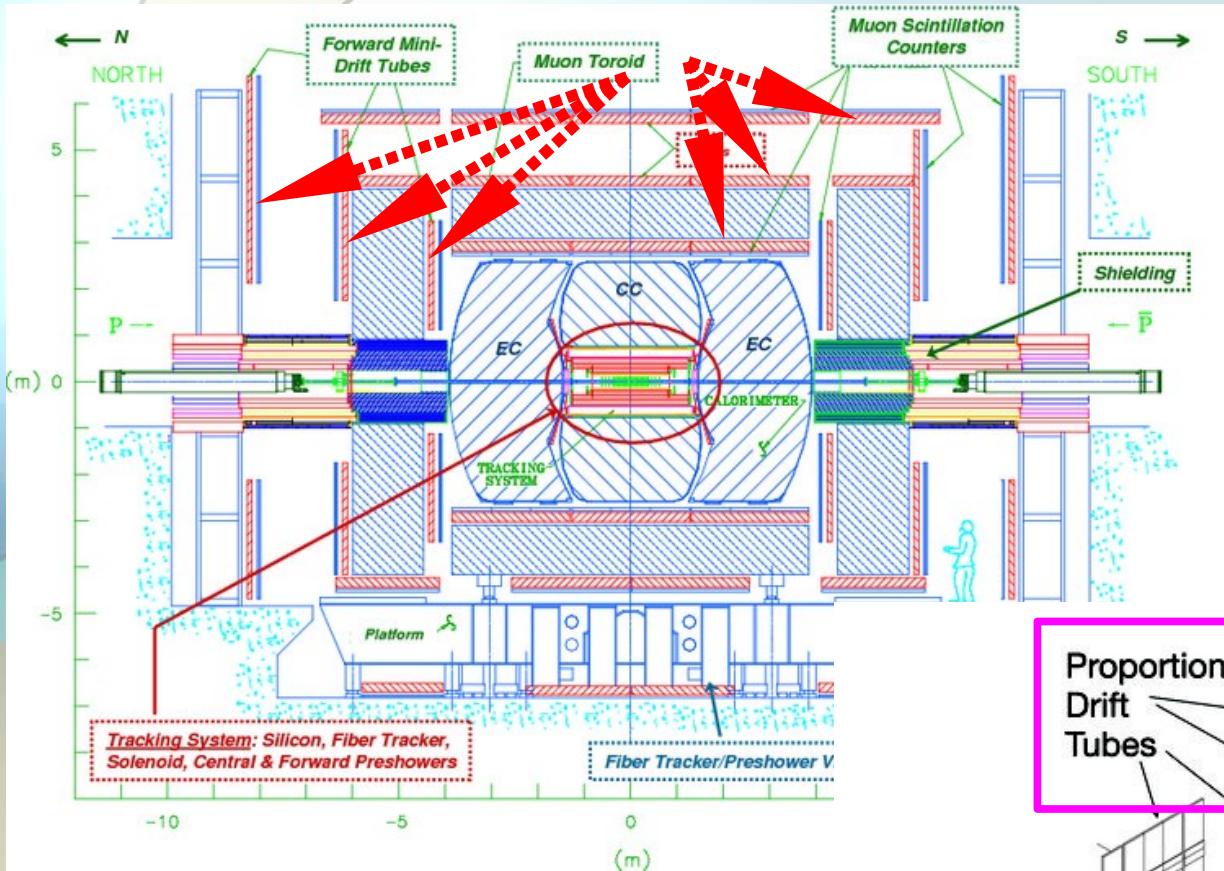
Sampling segmented Uranium – Liquid Argon Calorimeter

Energy measurement for photons,
electrons, and jets

Missing transverse energy for neutrinos



The D0 Detector: Muon Chambers

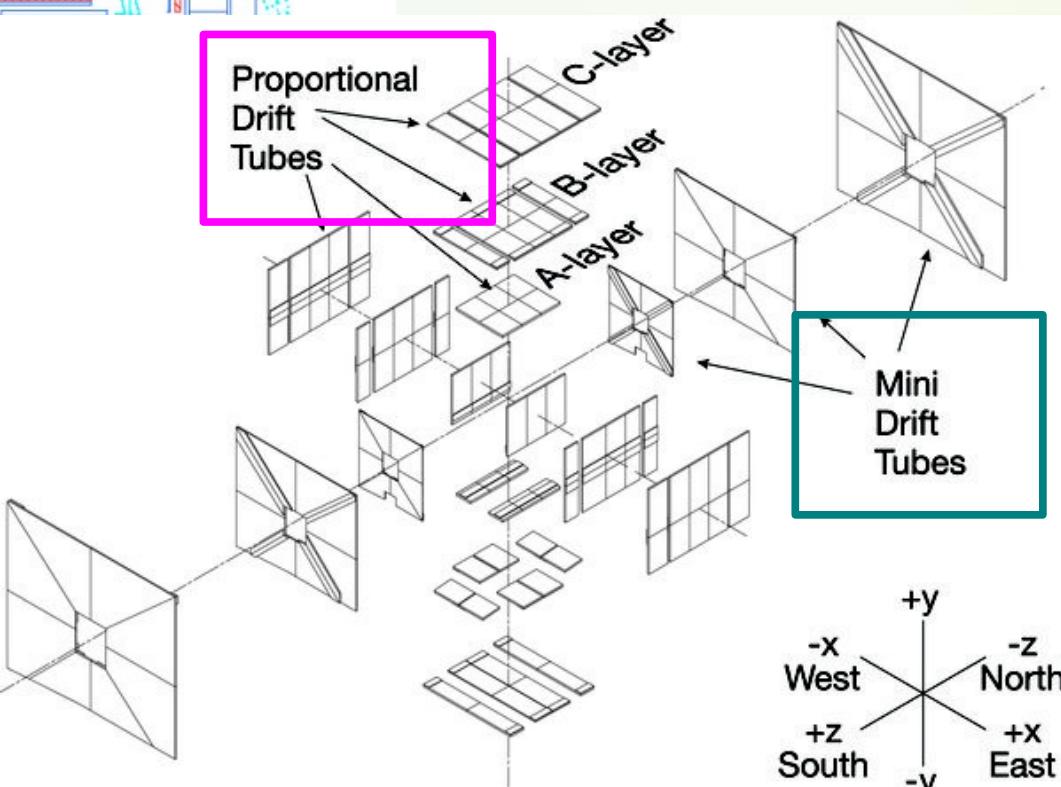


- 1) Central Muon
 $|\eta| < 1.0$
Proportional Drift Tubes
- 2) Forward Muon
 $1.0 < |\eta| < 2.0$
Mini Drift Tubes

Muons Chambers:

Drift Tubes and Scintillators 1 in and 2 outside of a Toroidal Magnet (1.8 Tesla)

Muons are reconstructed from hits in the muon chambers, matched to tracks in the inner tracking detectors.



Data Taking



Data acquisition rate is limited to 100 Hz (~ 12 MB/s data to tape)
→ 3 Level Trigger System



- **Hardware based**
- **Simple signatures in each sub-detector**
- **Software and Firmware based**
- **Physics objects: e, μ , jets, tracks**
- **Software based**
- **Simple version of reconstruction algorithms**